THE ROYAL AERONAUTICAL SOCIETY

(Founded 1866*)*

with which is incorporated the Institution of Aeronautical Engineers

VOLUME XXXVII

PROCEEDINGS

A meeting of the Royal Aeronautical Society was held in the Rooms of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, April 21st, 1932, when a lecture on ground organisation for aircraft operation was delivered by Squadron Leader Norman.

Colonel the Master of Sempill (Past-President of the Society) was in the chair.

The CHAIRMAN: The subject of the lecture was of great interest to all who were occupied with aviation, in whatever sphere; it was quite unnecessary to emphasise to such an audience the immense importance of perfecting the ground organisation for aircraft operation. The Society was peculiarly fortunate in that the lecture was to be delivered by Squadron Leader Norman, who had had an extensive experience of airport design and operation in this country, and had also studied the question intimately in Europe and, quite recently, in America. He had applied his knowledge to practice, for with his co-partner, Mr. Muntz, he had organised at Heston one of the finest, and in fact the first, private civil airport in this country, and had run it with great success and distinction. Therefore, he had every qualification to address the Society on the subject.

Squadron Leader NORMAN then delivered his lecture.

AIRPORT DEVELOPMENT*

BY

NIGEL NORMAN

In preparing this paper on Airport Development I have tried to adopt the point of view of that somewhat unsettled person who is, or I submit should be, employed to advise aerodrome proprietors and aircraft operators upon the special problems occurring in connection with airport design and construction. This person is variously known as an "aeronautical consultant," but I have encountered bodies of very definite opinion that he should be on the one hand an architect or on the other a civil engineer. I hope that it will in time become plain that although both these professional experts should be employed from the first in connection with the development of an airport, it is essential for the proper co-ordination of their different skills, and to preserve close co-operation between them and the users of the aerodrome that the principal engineer be a man whose studies have been devoted solely to the object in view, and whom I should prefer to describe as an "air planner."

I will not dwell upon those factors which determine the selection of an airport site. These have been admirably published from official and private sources. The value of proximity to the areas to be served, the importance of

* I wish to acknowledge the great help I have had in studying these problems from Mr. Graham Dawbarn, some of whose sketches have been used to illustrate the paper.

adequate communications and, indeed, the dimensions and characteristics of the ground needed to meet present-day requirements are well known. I am concerned with the development of the site when selected. Most of the illustrations have come from the United States, where I was recently able to examine a number of airports in company with Mr. Graham Dawbarn, F.R.I.B.A., whose name is well-known in connection with airport architecture. It is perhaps a sufficient reason that among some 1,800 aerodromes, it is easy to select examples to demonstrate any point one may wish to bring forward.

Airport development is controlled by three factors—the nature of the traffic to be dealt with, its volume, and the geographical and meteorological conditions which prevail at the site. Aerodrome traffic is insignificant at present, but in America it has reached rather larger figures than over here. At the major ports movements of scheduled traffic average from 95 to 60 per day, and on isolated occasions huge numbers of aircraft are concentrated at a single field.

Landing Area

The majority of airport planning is to be done within the boundaries of the airport site. It will be logical to begin with the part actually used by aircraft for landing. The minimum dimensions required for a licence for all types are slightly smaller in England than in America, where an effective landing run of at least 2,500ft. is required in eight directions, due allowance, of course, being made for obstructions, taking the gliding and climbing angle as 10 : 1. Where the landing area is laid out as runways, these are required to be 500ft. wide for a first class rating. Experience has shown that where a single runway is to be used for landing and taking-off, 400ft. is the minimum satisfactory dimension. These sizes, satisfactory with existing types of aircraft, may have to be increased in the future if the type of aircraft used alters to any extent. Already machines are in regular operation maintaining time-table schedules of very nearly 180 m.p.h. Such aircraft naturally take up most of the field when heavily loaded. They have, however, proved quite practicable and there is serious talk of developing even faster types. We in this country are using larger aircraft than the Americans and with an increase of traffic, one can easily picture three or four " Hannibals " tending rather to jostle one another on a 400ft. wide strip. The length of the landing area must also be varied where the airport is at any considerable altitude. Some examples of the extent to which it must be increased may be interesting. Taking an accepted calculation, for an altitude of 2,000ft. the length should be increased 10 per cent. ; for 4,000ft., 25 per cent. ; 6,000ft., 50 per cent. ; 7,500ft., 75 per cent. ; and 100 per cent. for 8,500ft. Although this factor is not important in this country, it applies seriously on a number of Empire air routes.

In view of the foregoing remarks, it would seem that in planning a major airport, a considerably larger area is desirable than has usually been possible in this country. The Americans, more fortunately placed than we in this respect, have taken due regard of the point, as the following figures show. Chicago, while using 160 acres, has reserved 640 acres. Kansas City has available 800 acres. Oakland (Fig. 1) has reserved 850 acres, while Indianapolis has allocated 947 acres. While these figures are undoubtedly extreme so far as landing area is concerned, this generous planning will certainly react to the advantage of the cities in question, since not only the airport itself, but all its surroundings, will be developed as a concrete whole.

Runways

In Europe our aerodromes, being surfaced with excellent turf, are available for landing in every direction. In other words, they are " all way " fields and the envy of the Americans, whose soil and weather conditions almost always

compel them to prepare specially surfaced strips as runways. There appears to be some doubt, however, as to the value of the two systems from a traffic point of view. At Cleveland, which is an " all way " field, I was told that it was only owing to this characteristic of the port that the tremendous traffic, amounting to as much as 950 movements in a day at the time of the National Air Races, could be handled. On the other hand, at Detroit, where a purely runway aerodrome has been developed on a narrow " L " shaped site (Fig. 22), it was explained to me that at the time of the annual Exposition, it was only by the systematic use of runways that it was possible to handle traffic averaging 200 movements hourly for seven consecutive hours and reaching 256 movements in the most crowded hour (one undoubtedly well worth an age without a name!).

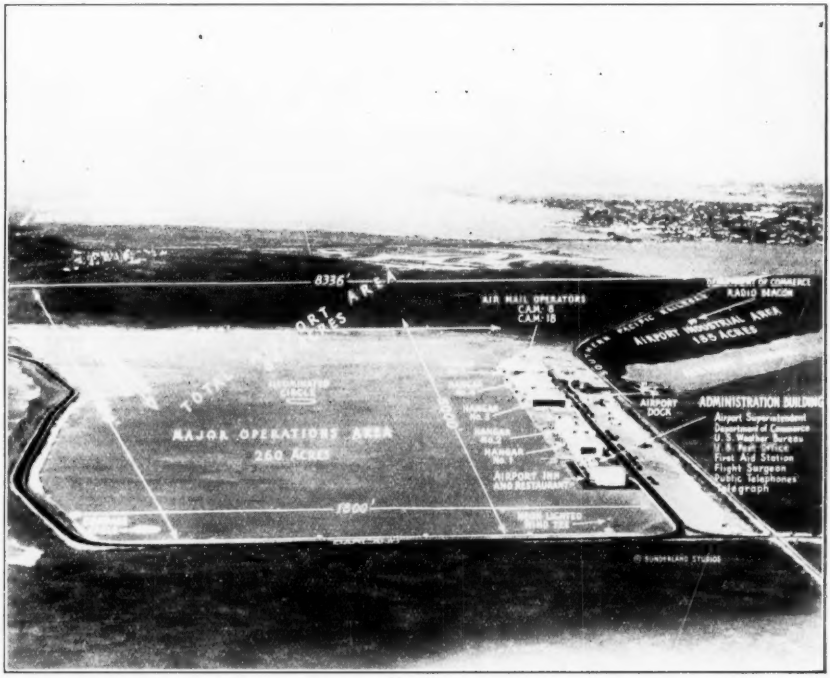


FIG. 1.

The airport area at Oakland on the mainland opposite San Francisco.

Taking into consideration the controlling factor of traffic volume, I personally believe that as the number of aircraft increases, it will become necessary clearly to mark flightways to be used even on an " all way " field and that even though these may not be specially surfaced, operations will follow the same procedure as on a runway field. This was actually encountered at Akron and at Toronto. It is usual, where single runway strips are provided, to use one side of the strip for landing and the other for take-offs. Alternatively, at a number of fields, two runways are laid out in each direction, and where this is done, the accepted practice is to allow at least 300ft. between the centres and to have each strip not less than 100ft. wide.

The materials in use for runway construction are numerous, but, in fact, the problem is exactly the same as the construction of highways for motor traffic. We were able to examine runways made of concrete, of so-called asphaltic concrete, of water-bound Macadam and of Macadam with Colas penetration, and also some made by compounding the surface soil with a spray of asphaltic oil. In some cases, three feet of ordinary cinders were used, while on emergency landing grounds in the desert areas of Arizona and New Mexico, the runways were sometimes merely of levelled and rolled sand. The construction to be adopted must obviously be dependent upon the availability of material and of the nature of the soil at the site. In sandy areas, where little rainfall is expected and drainage is simple, oil spray runways appeared extremely effective, their only disadvantage being that a surface of such uniform appearance is produced that there is some slight difficulty in judging distance for landing, the sensation being somewhat the same as when landing a seaplane on glassy water (Fig. 3). On clay subsoil, concrete would appear to be the best solution, and it was noticeable that this was often used where double runways had been planned. The suggestion that in each direction there should be runways of different material

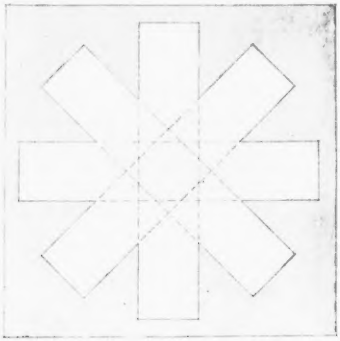


FIG. 1*a*.
Diagram of "Star" runway layout.

for landing and taking-off need not be taken seriously. Where asphalt or Macadam are used, a foundation of hard core or broken rock is, of course, necessary. Cinders appear to be the least satisfactory solution, requiring constant maintenance and being subject to a process of deterioration known as "rot," which gradually reduces them to powder. At one aerodrome, cinders treated with asphaltic oil were used, producing a satisfactory surface, but still apparently requiring a good deal of maintenance.

Pattern of Runways

The pattern in which runways are laid down does not appear to have been seriously considered at the earlier airports. If eight directions of landing were required, you had a Union Jack. Where only two intersecting runways were allowed for you might support St. George or St. Andrew. In more recent layouts, however, it is evident that the pattern has been carefully studied, and it has been found that a proper arrangement will allow considerable economy in the amount of material required, and at the same time make for greater convenience in operation. A theoretical example may be of interest. Fig. 1*a* shows diagrammatically four runways 2,500ft. long by 500ft. wide at 45° interval arranged as a symmetrical star. Fig. 4 shows the same pattern which allows

for more convenient spacing of the buildings. The control tower and terminal building would obviously be placed in the centre towards the bottom of the figure, while commercial and industrial buildings could be arranged along the sides without interfering with any of the flightways. In addition to allowing a more satisfactory layout, reducing taxying and facilitating control, the area of this figure is only 9/10ths of that of the star. It is possible to re-arrange these runways in an even more economical pattern occupying very little more than 4/5ths of the star area, but the resulting figure has not the advantages of the one just illustrated. It will be seen that a modification of this design has been employed at Kansas City, and at the newly-designed Shushan airport, New

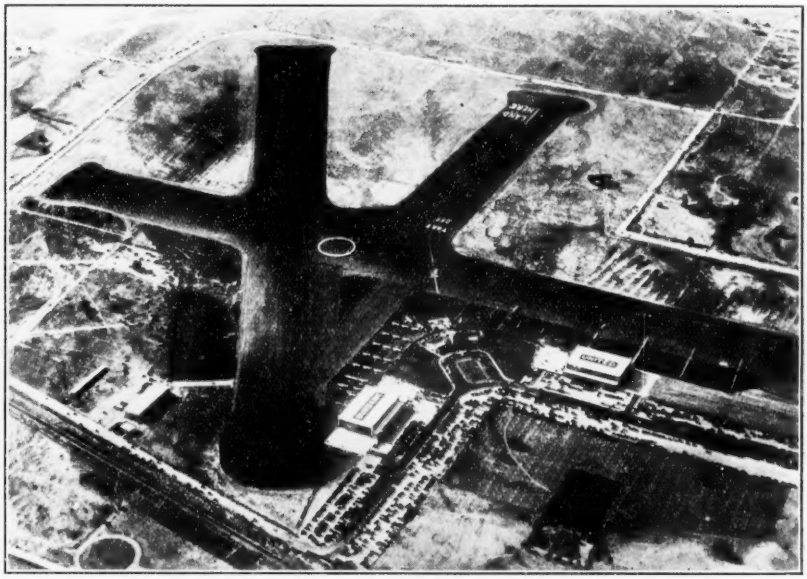


FIG. 2.

United Airport, Burbank, Cal., showing runways and the accessible position of the terminal building.

Orleans, while the new municipal airport at Pittsburg, possibly the most advanced layout in the world, employs a somewhat similar arrangement. The runway pattern will, of course, be subject to variation where meteorological conditions may allow the elimination of a certain number of directions of landing. Examples may be taken from California, where prevailing winds are almost invariably east and west. At Burbank (Fig. 2), a particularly fine airport, one runway indicated on the plan has never been constructed, while at Glendale, only a few miles away, only one strip is ever used at all. The new Pittsburg airport (Fig. 7) probably illustrates the logical development of a runway aerodrome, since the strips have been so widened as to cover practically the whole surface of the port. Each, however, is divided by a clearly marked line along its axis, which is intended to separate the landing from the taking-off area.

Drainage

While considering the landing area of the airport, reference must be made to an exceedingly important problem—that of drainage. The amount of drainage

required varies considerably with local conditions. It is almost always a major factor in the efficiency of the port. In this country where turf aerodromes are in use and where rainfall is moderate and evenly distributed, the problem is not a difficult one, although the standard required is much higher than that demanded for agricultural purposes. When the levels of an airport have been carefully plotted and contours drawn at a narrow interval, it is a simple matter to locate the main surface drains into which the water may be led by means of mole drains, agricultural open-pipe drains or clinker filled trenches. Each site must be specially considered, but it is to be noted that an absolutely flat area is the most difficult to deal with, and that gradual falls, which have no adverse effect in the movements of aircraft, may be used with valuable effect to assist in the disposal of surface water.

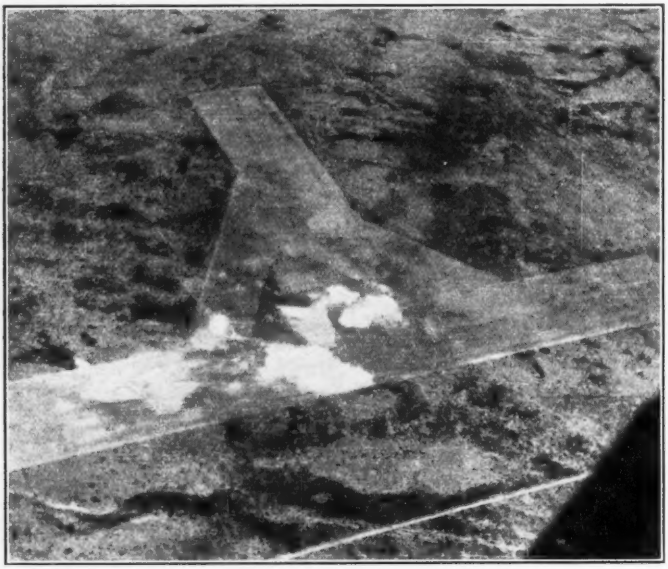


FIG. 3.
A typical emergency landing field in the desert area.

Where runways are concerned, the drainage problem becomes more complicated. The runways being non-absorbent, to avoid standing water they must be constructed with a crown three or four inches in height per 100ft. of width. The runway itself forms a considerable catchment area, and unless specially dealt with, water running from it will produce a sodden condition of the ground at each side, so that special drainage must be provided to take care of this point. The problem is somewhat the same where the concrete or asphalt apron in front of the buildings meets the aerodrome. Various suggestions have been made for the construction of a porous strip at each side of a hard surfaced runway to allow the water to percolate through into a drain below, but these strips being made of loose material, which is easily disturbed by passing traffic, are a constant nuisance, and it seems likely that the more satisfactory arrangement will be for the runway to be constructed to provide its own drainage channels and outlets. Where very large areas are hard surfaced, as in the case of an airport such as Pittsburg, or where a large area of apron is concerned,

the problem of dealing with storm water becomes similar to that encountered in a completely developed housing area. With no absorption and very little evaporation, provision must be made to carry away immediately large volumes of surface water, and in such cases, the drainage will present a special engineering problem and will materially affect the expense of the whole undertaking. As an example of the extent to which drainage may figure in the construction of an all-way landing field, the airport at Cleveland may be quoted. Here over a million feet of agricultural drains spaced 20ft. apart, were used; 15 miles of 15in. sewer at 40ft. spacing were laid; and over $3\frac{3}{4}$ miles of 4ft. sewer were put down to carry storm water into a neighbouring ravine.

Position of Buildings

The disposition of the buildings round the airport must be largely controlled by the plan of the flightways or runways. This again is a problem which was

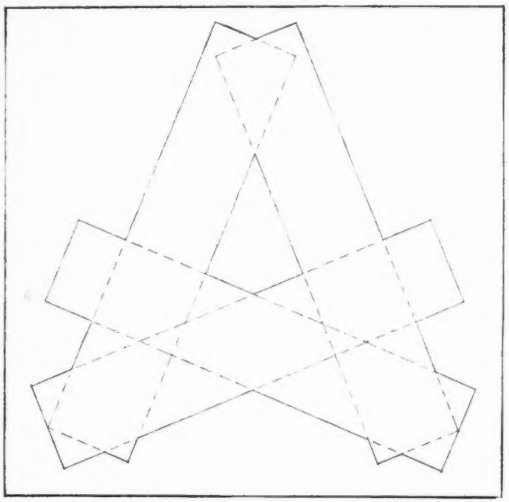


FIG. 4.

An economical runway pattern similar to that adopted at Shushan Airport New Orleans.

imperfectly understood when many American airports were constructed and many, as for example Chicago, have been envisaged merely as rectangular spaces surrounded by building lots. The result is tiresome in the extreme to the administration and to aircraft operators, and in my own case, it invariably happened that my machine had to be housed in a building at the opposite corner from where I arrived. At Chicago I lost an inch and a quarter of tail skid in taxying round two sides of the aerodrome and back.

Apart from the rectangular, two types of arrangement appear to be emerging into favour—first, and very much the most popular, the arrangement of buildings in a more or less blunt " V " intruding upon the landing area and having the terminal or station building at its apex. The other, adopted where particular circumstances make it desirable, allows for the buildings to be arranged in one or more rows stretching directly away from the landing ground. Examples of the blunt " V " are United Airport, Burbank, California, already illustrated

(Figs. 2 and 5), Buffalo Airport, San Francisco Bay, Shushan Airport, New Orleans, already referred to (Fig. 4), and Pittsburg Municipal Airport (Fig. 7). A particularly striking example of the second arrangement is at Detroit (Fig. 22), which at present uses one tremendous hangar block 200,000 sq. ft. in area and is planned for a second similar one in the future. The same tendency is illustrated at Indianapolis (Fig. 6). In the illustrations given, only one or two blocks of buildings are shown, but it is obvious that as traffic develops, the demand for hangar and administrative accommodation will absorb the whole perimeter of the airport, and that a number of similar though possibly less important

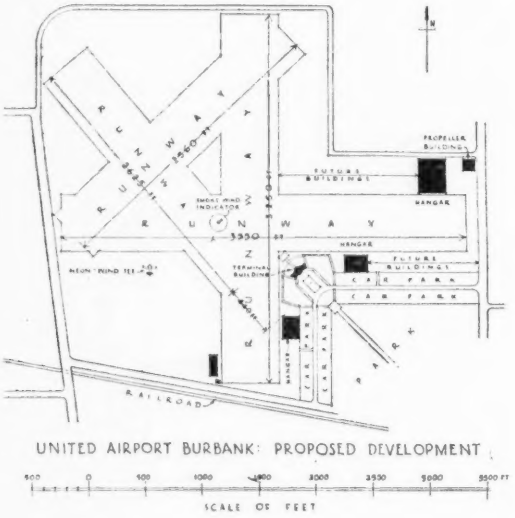


FIG. 5.
Plan of United Airport, Burbank, Cal.

blocks will ultimately be developed. Such an arrangement has the following advantages:—

1. That it offers a number of particularly accessible sites for control and terminal buildings, whose situation near to the centre of the landing area must reduce taxying and increase speedy operation.
2. That it gives a longer coast line to the airport, thus allowing for increased revenue, since the amount of frontage available must ultimately determine the earning power of a fully developed port.

In the light of these observations, it is interesting to examine the plan of the famous Tempelhof Aerodrome in Berlin, where, although the rectangular arrangement has been followed, an area in front of the main building has been restricted from use for landing. The effect of the arrangement seems to have been to sterilise this piece of ground for all purposes except unnecessary taxying.

Terminal Building

Turning to the buildings themselves, their position is likely to be determined by their relative importance from the traffic point of view. If we reject what I have termed the " rectangular " type of plan, in which all buildings are equally distant from the landing area, we shall find that the arrangement will

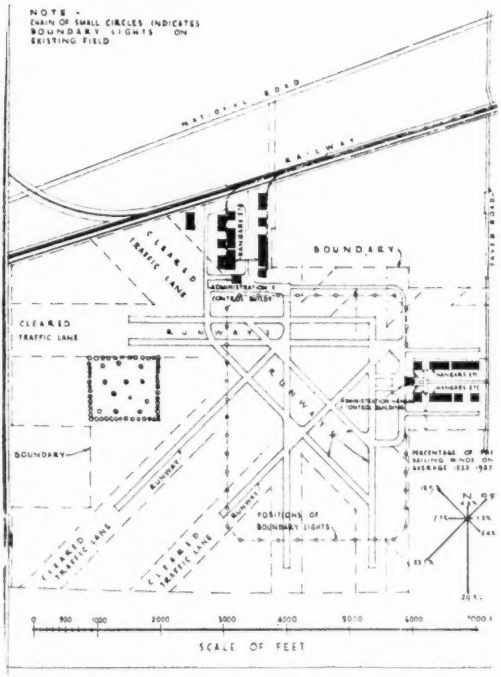


FIG. 6.
Plan of proposed development of Indianapolis.

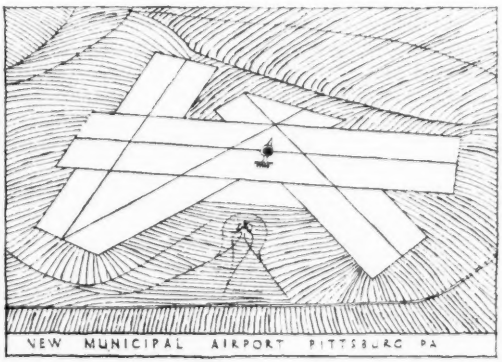


FIG. 7.
Sketch showing an oblique view of the new municipal airport at Pittsburg.

always offer one or more sites most accessible to air traffic and dominating the area to be used for landing. This site will be at the inner end of a block of building development. One site usually occupies the most important position of all, and this obviously should be reserved for the terminal building and chief airport station. Such a terminal building will house traffic control and airport administration, and no doubt provide passenger facilities for the more important air traffic. Backward from this may be placed hangars and workshop buildings which will themselves require administrative accommodation as well as space needed for aircraft.

In terminal buildings, it has been found necessary to provide accommodation divided broadly into three classes:—

1. Administrative accommodation.
2. Passenger accommodation.
3. Accommodation for sight-seeing public, whose presence as spectators is only valuable for propaganda purposes and in so far as a small revenue is derived from their entertainment.

FIG. 8.

The terminal building at Akron, Ohio. The floodlight and the recording instruments of the meteorological station can be clearly seen.

At the present time the volume of air traffic handled at important airports has been so small that the importance of the sight-seer has occupied an exaggerated position in the plan. At the great German airports, such as Tempelhof, Hamburg and Munich, possibly the major portion of the magnificent terminal buildings has been designed to cater for their needs. But as air travel becomes more popular and the spectacle of its operation more commonplace, the sight-seer will diminish in importance and it seems probable that the plan originally adopted at Croydon of catering for the outside public in an entirely separate building, may offer the final solution. In America we found a tendency to design these buildings on a well thought out plan, but on a scale much smaller than has been adopted on the Continent, thus making them more commensurate with present-day traffic needs. Details of design are particularly a matter for the attention of the aerodrome architect and, in fact, are his greatest opportunity. It may be of interest to examine some examples, in varied architectural style, but it is only proposed to discuss the accommodation provided in so far as it is affected by traffic requirements. As an example of a building designed to fulfil the present

needs of a non-airway aerodrome and for expansion later, I include at this point two views of the newly erected control building at Brooklands (Figs. 8*a* and 8*b*). The design is by Graham Dawbarn, F.R.I.B.A.

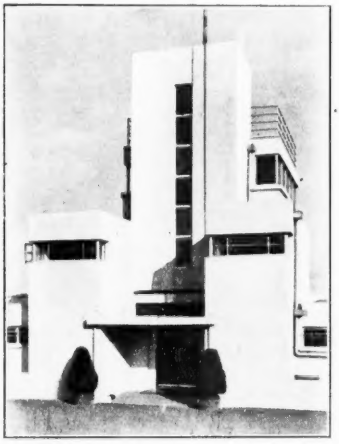


FIG. 8*a*.
View of the back of the airport building at Brooklands.

FIG. 8*b*.
View of the front of the airport building at Brooklands.

Control Tower

The control tower houses, as it were, the eyes and brain of the airport. With radio telephony becoming more and more essential to aircraft operation and with the increase of night air traffic, the tower must be laid out to bring into convenient juxtaposition wireless, telephone and probably public address apparatus and controls for lighting and signalling equipment. It is desirable for the meteorological office to be in close proximity. In addition to a plotting and record-room, out of doors a more or less undisturbed air flow is needed for the

heads of wind recording instruments, as well as a suitable roof for the release and observation of pilot balloons. In America, where the teletype, or electrical distant-controlled typewriter, is such an important part of the weather reporting system, a separate room, housing up to eight or ten of these instruments, is required at major airports. These problems seem to have been more or less successfully solved at a number of stations since the full range of apparatus is required to serve even a small amount of traffic (Fig. 9).

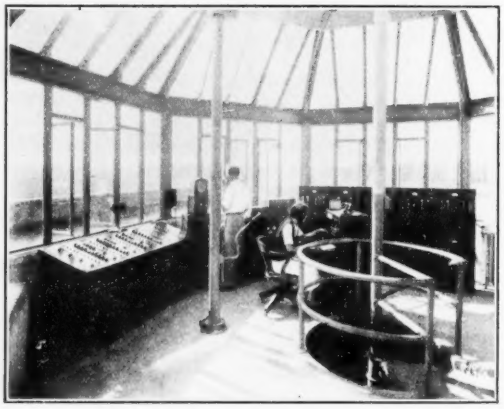


FIG. 9.
Interior of the control tower at Wayne County.

Passenger Handling

Where passenger accommodation is concerned, on the other hand, I believe there are considerable developments to come. Originally air liners arrived singly and at long and irregular intervals. The passenger was happy to begin his air adventure by half-an-hour's wait out of doors, until the blast of a propeller and showers of mud or dust heralded the approach of the monster that was to carry him into the unknown. Aircraft unprovided with brakes and difficult to manœuvre would stop sometimes in one position and sometimes in another. As air traffic became more highly organised, a more regular and orderly procedure became necessary, and to-day at an airport such as Croydon, the excellent organisation and the courtesy and efficiency of the officials conceals the shortcomings of a building designed some years ago.

In America the same inadequacy was noticeable at a number of the older stations and was not always compensated for by the organisation. At the more newly constructed terminals, however, a process of evolution is observable. At first, where a single machine was to be dealt with at a time, it was found possible to station it always at identically the same point. This was marked by strips painted on the ground, sometimes defining the actual wheel tracks. In view of this, it was a simple matter to set sockets in the apron and to erect at the last moment a fence of posts and chains which effectively guided passengers towards the cabin. Inclement weather conditions made it desirable to offer some protection to the passengers, and the Americans therefore began to erect canvas-covered canopies of the kind so frequently seen outside the doors of hotels and residences in New York. In order to allow these canopies to reach right up to the fuselage of the aircraft after it had taxied into position, it was found convenient to mount the outer sections of the canopy on wheels or rollers, so that

they might be extended in a telescopic manner. The result achieved seems very satisfactory, for by means of these extensible loading canopies, passengers are able to proceed from the station building right into the cabin of the aircraft without being for a moment exposed to wind or rain (Fig. 10).

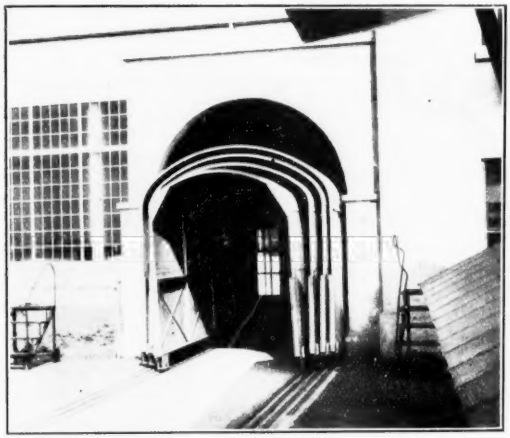


FIG. 10.
A typical loading canopy at Oakland Municipal Airport.

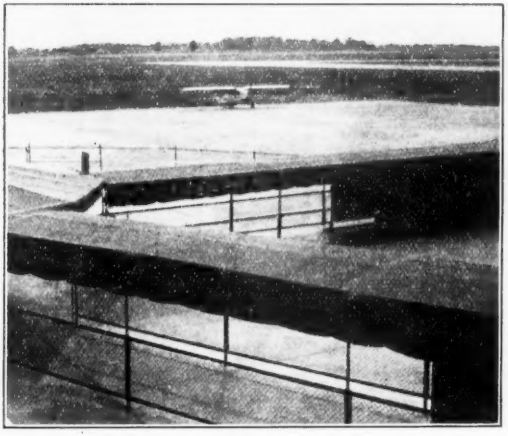


FIG. 11.
Part of a "bull pen" with three loading canopies at Indianapolis.

This is the first stage of evolution. The second stage began when it was found that several aeroplanes had at times to be loaded simultaneously. This state of affairs is an inevitable one where air transport is concerned, since where time is of vital importance and passengers are to be transferred from one service

to another at a busy traffic junction, the arrivals and departures must be timed as far as possible to synchronise. It was therefore found desirable to erect in front of the terminal building a semi-circular fence enclosing an area colloquially known as the "bull pen," the fence being provided with a number of gates opposite which aircraft could be stationed for loading (Fig. 11). Obviously each of these loading points should be provided with an extensible canopy, and for the greater comfort of those waiting to embark, the whole bull pen itself might well be roofed and protected from the weather.

The tremendous flow of money towards aerodrome development unfortunately ceased in America a little before this final stage was completed, and although there are at several airports bull pens with more than one loading canopy, the logical development of the idea has not yet been worked out. I submit, however, that this completion is inevitable. Where it is a perfectly simple matter to protect passengers at all stages of their journey from exposure to weather, it is certain that they will demand protection. Skirts need not be worn suddenly over

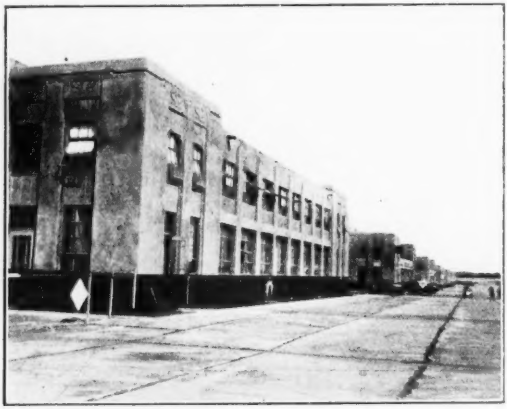


FIG. 12.

View of hangars at Roosevelt Field looking along the apron.

the head, and new Paris hats should be protected from rain at least until they have escaped the customs officials. There is very little doubt that the proper development of passenger handling facilities on these lines will greatly simplify operation and improve the working conditions for operating staff. It seems likely that what was originally the bull pen will become transformed rather in accordance with the principles of railway station design into what is known as a "circulating area." This area will be used to accommodate the immediate needs of passengers and their friends for newspapers, postal and telegraph facilities, etc. From it will lead off a number of loading canopies which will be clearly marked after the manner of platform entrances, with particulars as to the destination and time of departure of the respective service. Approach to the canopies will be controlled by gates, and where customs traffic is being dealt with there will, no doubt, be a dividing barrier between the waiting public and the arriving passengers, arranged in the same manner as at railway platforms where continental traffic is handled. The plan of the whole area will, of course, be carefully devised to provide separate and convenient avenues for other classes of traffic, such as parcels traffic, freight and mails. As development proceeds,

construction of the canopies may become more elaborate and steel and glass may replace canvas. Alternatively, they may be replaced by underground tunnels leading to the points of embarkation. At an airport such as Croydon it would seem desirable to provide, in the very near future, for the simultaneous loading of four or five machines and for an ultimate capacity of twice this number.

Although this prophecy conjures up visions of most elaborate construction, it is worth remembering that an arrangement providing in a more or less temporary manner the practical advantages of the scheme will not be at all expensive.

FIG. 13.

Plan of the large hangar at United Airport, Burbank, Cal.

Probably the requirements outlined above, together with the tendency for terminal and station buildings to occupy sites projecting inwards towards the landing area, will influence these buildings to a plan rather convex than concave. Of this Burbank, Buffalo and Lyons are examples. I am indebted to Mr. John Dower, A.R.I.B.A., for a plan of the latter port (Fig. 5). I have always thought it an exceptionally interesting and ingenious design. For this reason rather than for the remarkable quality of its cuisine, I strongly recommend architects to study it sympathetically.

Hangars

Leaving the terminal building now in the hands of these gentlemen, we may turn to the buildings designed to accommodate aircraft. The essential features of a hangar have been said to be those of a box upside down, of which one or more sides will open. The main problems are seen, therefore, to be first, the

size of the box, and secondly, the manner of its opening. The first noticeable tendency when an examination of types of hangar is made is that they are getting larger and larger. In spite of the prophecy that big aircraft will be treated as ships and moored out of doors all their life, there is a continued reluctance on the part of operators to expose their fleets to the weather, and designers are producing wider and wider spans and larger door openings in anticipation of the trend of aircraft design. While the number and dimensions of hangars is controlled by the nature and volume of traffic, it seems to me that among the many different forms of construction which have been used throughout the world, selection would depend upon a third and even more important factor—I refer to that of cost.

The nature of hangar requirements is likely to vary more than that of other facilities as the result of local conditions. It is noticeable whatever the size and purposes of a hangar, some administrative or workshop accommodation is always required in connection with its use. This fact, which has long been appreciated

FIG. 14.

Municipal hangar at Detroit.

in America, is likely to influence design considerably. In the United States the tendency has been to construct an office block at each or one end of the building. Owing to the height of hangars such blocks can usually be constructed with several floors, the planning, of course, being controlled by the activities which are to take place in it. It seems likely that since deep trusses are required to bridge the wide spans of modern hangars, space otherwise wasted in the roof can be conveniently used for office purposes. Where a building is to be used for service and repair work, it is likely that a complete upper floor may be desirable, although I have not yet seen a building constructed on this principle.

In this connection I would emphasise that it is by no means certain that all airport buildings should be low. Demand for accommodation will necessitate several storeys in time to come; and if correctly planned, such buildings will add to the efficiency as well as to the appearance of an airport design.

For all large buildings steel construction has been adopted in America, and in some cases very interesting designs have been used. In the large hangar at Burbank, Cal., an area the size of a football ground is covered by a steel structure having only four supporting pillars arranged some 60ft. in from the doors. The steel work is of a very complex sort of umbrella design, using com-

paratively light sections. There is no doubt that a building of this kind offers a fascinating problem for the constructional engineer. As examples of other large buildings, the main hangar at Detroit of 200,000 square feet of floor area and a new building at Kansas City, 390ft. by 170ft., may be quoted. In France I have seen examples of very fine buildings of reinforced concrete construction with brick or tiled infilling, but as these were military hangars, I have unfortunately no illustrations. Considerable efforts have been made to construct hangars beautiful as well as useful, and while this " Adams " design seems a little incongruous, the hangar at Cleveland, of severely classical proportions,

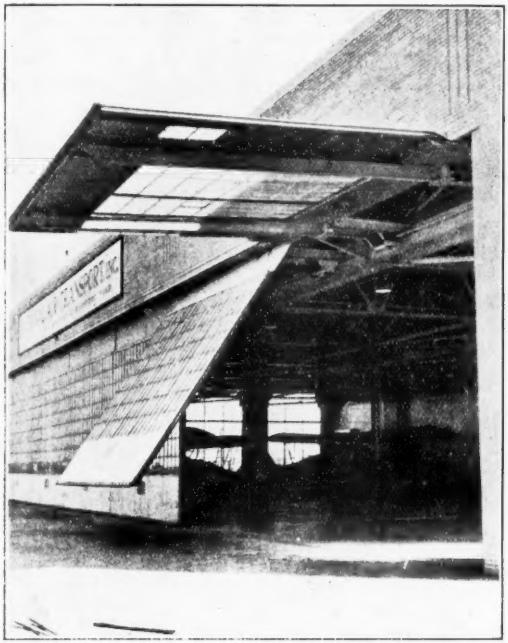


FIG. 15.
Canopy doors to hangar at Cleveland designed by the Austin Company.

is fine to look at as well as most efficient in use. Its one item of decoration was, I thought, effective. In examining the problem generally in America, it strikes one that the more recently constructed buildings have been of much less ambitious design than those put up a few years ago. For instance, the hangars at the new airport at San Francisco Bay are proving satisfactory in use, and, covered with corrugated asbestos, must have cost very much less per square foot than those previously referred to. As a successful combination of artistic effect with economical construction, I consider the hangar of corrugated asbestos at Sacramento to be outstanding (Fig. 17). Hangar cost bears directly upon operating costs, which leads one to think that buildings of this type of construction will be popular for some time to come.

Doors

From an operational point of view, perhaps the most important feature of the hangar is its doors. These may be constructed in panels supported on overhead or ground tracks, and running on rails to the sides. Alternatively, they may be constructed in small sections hinged together and arranged to close up like a concertina at the sides of the opening. A very striking form of doorway, known as the " overhead canopy " door, was seen in America, and appeared to be ideal from an operational point of view. The illustration (Fig. 15) shows the way in which the doors open, control being by a series of electric push buttons. Such a form of door is costly and may perhaps be regarded as a luxury at the present time. A difficult situation might arise in the event of failure of the electrical operating mechanism. From the point of view of expense, which, as has been said, may finally control design, doors supported at the bottom are likely to be cheaper than those hung from above, and there appears to be no reason why, with proper maintenance of the track and operating gear, they should not be absolutely satisfactory in use.

FIG. 16.

Fire protection.
Automatic sprays in action in the Detroit municipal hangar.

Fire Protection

Where very large areas are enclosed, protection against fire is of increasing importance. Elaborate spray installations automatically controlled and similar to those employed in warehouses and stores have been installed in a number of American hangars. The methods employed are well illustrated by the arrangements in the municipal hangar at Detroit (Fig. 16). A system of pipes and jets is fixed in the steelwork of the roof and a similar system is laid in the cement of the floor, the jets being covered by small hinged flaps. Control of the whole apparatus is automatic and is particularly interesting in this instance, since the releasing mechanism is actuated not by the fusible link method when a predetermined high temperature is reached, but by an apparatus depending upon the rate of rise in temperature. Experiments with fires of petrol and aeroplane material have proved the system to be absolutely effective within comparatively few seconds, as might well be supposed from this illustration of the mechanism in action.

Heating

Hangar heating presents particular problems, first because the fire hazard must be eliminated, and secondly because an opening of large door areas may lead to a sudden drop in temperature unless very extensive reserve heating is available. The use of hot water or steam pipes has not proved sufficiently flexible to be effective. Hot air distributed by overhead ducts from a central heating chamber, where oil, coal or gas is consumed, has been found the most satisfactory method. The location of the hot air outlets is important. These should be arranged close to the door openings, discharging inwards. An interesting alternative method is, I believe, in use at Halle-Leipzig, in Germany, where a curtain of hot air is discharged from the floor opposite the door opening.

FIG. 17.
A simple type of combined building at Sacramento.

Hangars may be so positioned that the doors open directly towards the landing area, or alternatively, they may be placed at right angles to the main apron with door openings on to intervening spaces between them. The latter arrangement is much favoured in America, and has much to recommend it. It enables door openings to be constructed at both sides of the hangar. If the administrative accommodation is arranged at the ends of the building, it allows one block to face the aerodrome, which is usually convenient, and if the building is long in comparison to its width, the arrangement is economical of aerodrome frontage. Where a hangar is designed to house aircraft which are in daily use, the door area should be as large as possible in comparison with the area of the hangar, and opening on both sides is desirable. In workshop hangars, on the other hand, a much deeper building with opening on only one side would probably be found convenient. This arrangement fits in well, since considerable workshop, stores and administrative accommodation is required adjacent to the working area.

Combined Building

Where a limited traffic is to be handled on a newly-constructed airport, a special kind of building has been evolved in America which has not appeared over here. This is a combined hangar and terminal building. Although some difficulty arises owing to road vehicles and aircraft intermingling on the apron, the

arrangement is impressive in practice and some very fine examples of this type of building are in use. It would appear particularly suited to an intermediate station on a main through airway, and in such circumstances would prove economical owing to the improved accessibility provided by a single unit, and simplification of heating, lighting and other services. The illustrations are of buildings of this type at Indianapolis (Fig. 17) and one at Wayne County airport (Fig. 18), near Detroit. A modification of this type can be used where an aeronautical company provides its own passenger accommodation in a separate building on a large airport. The Boeing System building, at Oakland, illustrates a building which houses at the same time the company's aircraft, a complete passenger station and a large aeronautical and engineering school.

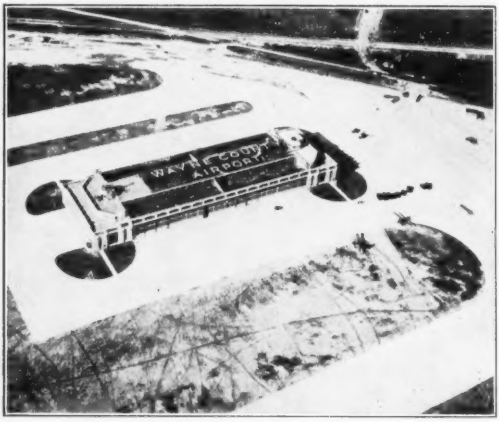


FIG. 18.

The terminal building combining hangar, administration and control tower at Wayne County.

Wind Indication

In considering airport equipment, the first and most important item is proper indication of wind direction, since an absolutely clearly defined direction for landing at all times is the first essential to proper traffic control and safe operation. The old-fashioned wind sleeve, suitable for the country landing field, is inadequate to the requirements of an airport. An apparatus is needed which in conditions of normal visibility can be seen clearly from several miles away, showing distinctly the direction into which aircraft must land whatever wind may be blowing. The most dangerous time is when there is no wind at all, since pilots, unless rigidly controlled, may be inclined to take-off or land in whatever direction is most convenient to them. In normal circumstances, a smoke pot in the centre of the aerodrome is an admirable wind indicator, but in conditions of flat calm or in gales and snow, I do not consider its indication to be sufficiently definite to be absolutely satisfactory. Also it is difficult to illuminate at night. It seems, therefore, that the best arrangement is a large " T " or other shaped indicator pivoted to swing into the prevailing wind or in a calm to take up some predetermined position. In my opinion, wind indicators should be very much larger than they are at present, and when I discussed the matter with American airport managers, I found support for this view. For a large airport, an indicator 60 to 100ft. long, displayed in the most prominent position possible, would seem desirable.

Night Lighting

Operation of aircraft at night is increasing rapidly. In America 25 per cent. of the scheduled traffic is flown after dark. In spite of the volume of this traffic, however, a number of different systems of night lighting are in use, and no doubt considerable further development will take place before a universal method is arrived at. A system of boundary and obstruction lights is, of course, essential. On certain runway airports the runways themselves are outlined by small lights. A row on each side of the runway have been mounted in the same way as boundary lights, while another method is to sink lights in the centre of the runway 100ft. apart and mounted in flush type fittings which are able to withstand the passage of aeroplanes. This last system I found to be universally approved by pilots. It was emphasised, however, that wherever any volume of traffic is to

FIG. 19.

Floodlight with shadow bar operated by hand winding gear at Indianapolis Airport.

be handled, a degree of general floodlighting is essential. At some ports this was produced by a number of independent projectors of the commercial type, mounted in groups and fixed with divergent beams to cover the required area, while at others a large floodlight unit with dioptric lens was employed. The latter system appears to be gaining in popularity. The use of mobile floodlight units has been abandoned in America as too cumbersome in operation, where the light may be required at a number of points at short intervals all through the night. The alternative has been to have two or three floodlights in permanent mountings at positions where they will provide jointly or separately the illumination required for landing in any direction. Alternatively a single floodlight is used, mounted upon or adjacent to the terminal building. The normal practice is to mount the floodlight from 10 to 30ft. above the ground, which improves the effect of the illumination, although one would have thought that it would make landing difficult where ground mist is encountered. A device is incorporated in the lamp to eliminate dazzle from the pilot even when he is landing approximately towards the light. This system is the more economical of the two and has the added advantage that it protects the pilot of the machine from all glare which may be reflected from the wings and windscreen of the aircraft when landings are being made by an ordinary floodlight. It is curious that this system

of night lighting, though economical and popular in use in America, has not been introduced before in Europe.

Another important feature of night lighting is the airport beacon, usually of the rotating or flashing type, and mounted upon the terminal building. Neon beacons have not proved of much value, and at the present time I doubt if any more valuable type could be found than those illustrated to this Society a short time ago by Dr. Benkendorf. It is essential, of course, that the wind indicator be adequately illuminated at night. At some airports this is used as a means of signalling to pilots that conditions are favourable or unfavourable for landing. In the former case, the wind indicator is lit by green Neon tubes, while if dangerous conditions prevail, the colour is changed to red.

FIG. 20.
Standard beacon tower and petrol depot.

Wireless Telegraphy

An item which must early engage the attention of the air planner is the airport wireless station. Where a beacon is to be installed, there would appear to be a good deal to be said in favour of its installation in the centre of the major building block, where its aerials could extend above the approach road and car parking area and where, though near the centre of the landing area, it would cause the minimum obstruction to flying. The aerials of the airport transmitter station could conveniently be arranged some distance from the aerodrome. In this connection, it is notable that in America where several air companies were operating on the same port, each had its own radio transmitting station,

and although several worked on the same wave length at the control tower, no confusion seemed to result.

Fuel Supply

The provision of suitable fuel supply points has been a problem of aerodrome designers in the past. For the small type of aeroplane, pumps with overhead swing arms have proved satisfactory, but these are useless for larger machines. Underground supply to a host pit located well out on the apron has proved satisfactory up to a point and is widely used in Europe and America. Several proprietary forms of pit with meter and hose reel are satisfactory in use, in

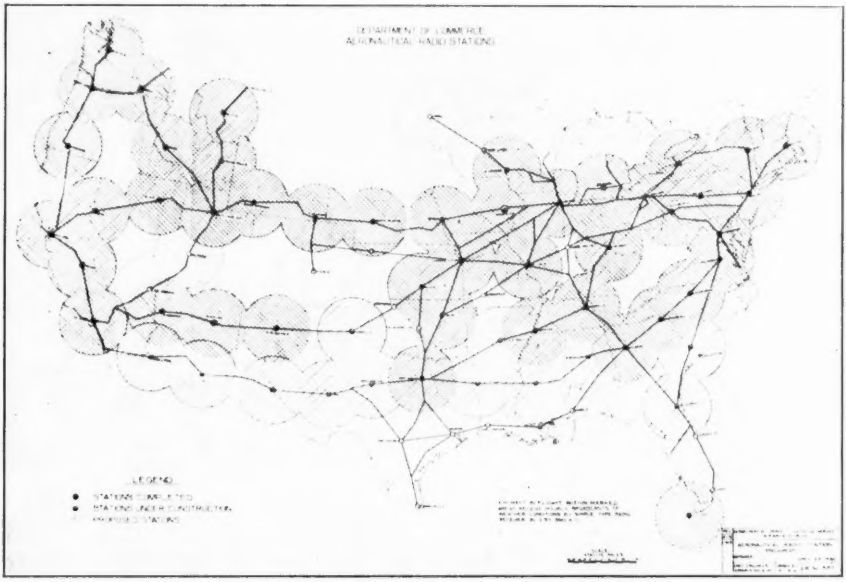


FIG. 21.

The chain of Department of Commerce wireless stations on the main airways routes.

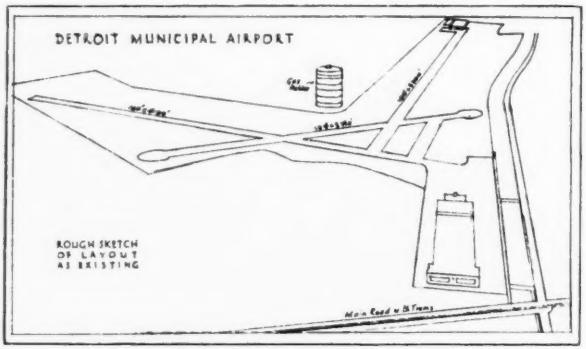
(NOTE: *The diagram was prepared in* 1930, *but practically all the stations are now in operation.*)

spite of the problem of drainage of the pit and the risk of excessive wear of the expensive hose employed. There is to-day, however, a marked tendency to abandon the practice of bringing the aircraft to the fuel point in favour of the rather more logical method of bringing the fuel to the machine in a specially constructed lorry. I think there is little doubt that this method will supersede the fixed refuelling point, although bulk storage may still be necessary in the vicinity of the airport. Those generally in use carried oil as well as " gas " and gave rapid and efficient service.

Town Planning

We have now considered the planning of the airport within its boundaries and looked for a moment at the different types of building that may surround it.

The more important items of equipment have been superficially dealt with, and it only remains to view the airport as a co-ordinated whole in the plan of the area it serves. Its importance so far has not generally been sufficient to ensure in practice that degree of consideration which is necessary for ideal planning. If the future is to be rightly provided for, it is now that steps should be taken, for the airport will undoubtedly exercise an important influence upon the sur-



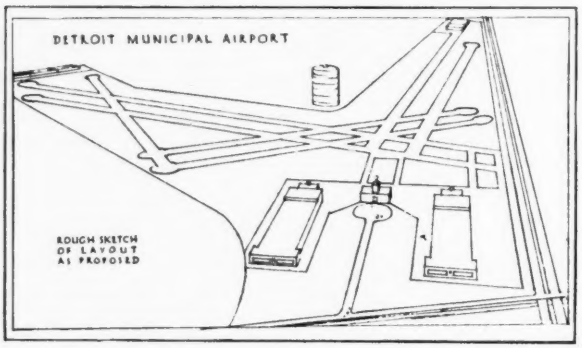


FIG. 22.

Sketch giving an oblique view of Detroit Municipal Airport, present and future.

rounding district. This is likely to become in time completely developed, and the plan should certainly be drawn so that the open spaces allowed for may be in co-ordination with the requirements of air traffic. Near the landing ground, lanes of approach should be zoned to prevent the construction of very high buildings which may cause obstruction. The necessity for forced landing grounds in the near vicinity suggests that open spaces should be located as nearly as possible in prolongation of the flightways. A very practical method has been suggested, and, I believe, adopted at Detroit, where the airport is right inside

the city. Boulevards, formed of two roads with a wide space of grass between, are being planned to lead away from the airport in such a manner as to give forced landing grounds for machines taking-off. It seems likely that if this process is further developed, chains of open spaces will come into existence forming, as it were, avenues of approach or air lanes leading through developed areas to the airport.

There is a further requirement which seems to me likely, although I have not seen it referred to before. I believe that for the proper control of aerial traffic in the future, signalling stations will be required at some distance from the boundary of the airport to indicate to approaching aircraft the beginning of the landing zone at the moment in use and to show the exact line of approach to be followed.

FIG. 23.
A typical American air sign.

From another point of view, the airport should offer an attractive opportunity to the town planner. As a huge open space the surroundings of which are perhaps less suitable for residential than for other purposes, it would seem to be an ideal basis for development of park and recreational areas. In this connection the example of Akron is interesting. This town being the home of the great American airship, the inhabitants have become fired with determination to develop to the fullest possible extent their air centre. The aerodrome itself is large, and besides the enormous airship shed has an excellent terminal building, already illustrated. The plan of the airport has been somewhat controlled by the fact that the ground rises to the south and west. Double runways have been planned and the hangars set back under the lee of the hill. The surrounding area has been very carefully laid out by the Town Park Committee. A fine boulevard is being built to lead round the brow of the hill, and at a commanding point the city's war memorial is located. Between this road and the aerodrome, the country is being developed as a public park. A convenient depression in the ground is being made into an open-air stadium, while a hill at another point is being specially arranged as a camping ground for visitors. The equipment of the area for camping includes elaborate provisions for water supply and sanitary arrangements. At another point the park is being specially equipped for picnickers. Here also the equipment is complete, for each pitch is provided with a gas stove and a set of utensils. The attractive surroundings, the wide views

and the varied facilities available will undoubtedly make this airport the recreational centre of the whole district, although first class communications maintain it in close relation to the business centre of the town. Different treatment may appeal to other planners, but I think this is the right spirit in which to approach the problem. The whole development of aviation is taking place so rapidly and the path of progress is so easily affected by new discoveries that it is rash indeed to suggest the correct solutions to many of its problems.

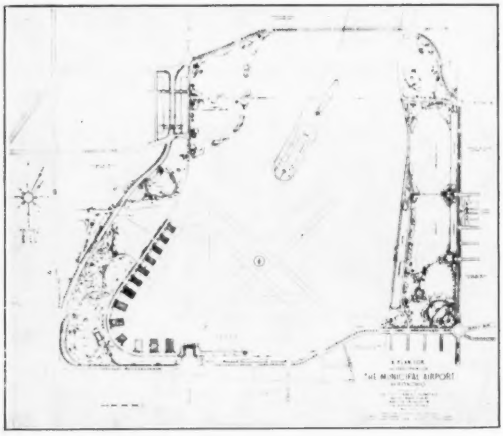


FIG. 24.
Plan of the Municipal Airport at Akron, Ohio.

If I have to-night particularly stressed the views which have governed American development, and interpolated at times tentative ideas of my own, it has not been with the object of finally stating what has got to be done, but with the quite contrary intention of stimulating interest in the fascinating question of air development on the ground, so much less studied in the past than the air. I am prepared to be confounded on every point if only the correct solutions are widely published and the minds of those responsible made fully aware of the necessity for present action to meet the certain needs of future generations.

DISCUSSION

Wing Commander ALLEN (Directorate of Civil Aviation) offered his heartiest congratulations to Squadron Leader Norman for his extremely interesting lecture, containing an enormous amount of hard, solid facts. He emphasised that what was done in this country would quite probably have its reaction throughout the Empire. Just as the consulting engineers of this country were implicated in the building of bridges and other structures in Australia, South Africa, and so on, so he hoped to see the aerodrome planners of this country going out to assist the great Dominions and Colonies. When they found themselves planning airports in those places they would probably come up against difficulties in respect of the soil. The black cotton soil and the various other types of soil in India, the Malay States and in Africa would probably give rise to some of the greatest difficulties. There was a tremendous field for the study of methods of dealing with these difficult soils, which were all right for perhaps nine months in the year, but which were in a condition impossible of description during the remaining three months.

Mr. IVOR MCCLURE: He was a little puzzled as to whether the use of runways would be universal in the future. All the aerodromes illustrated by Squadron Leader Norman had been provided with runways, and there seemed to be very few aerodromes on which machines could land in every direction. That, of course, was bound to affect the design of aircraft. This state of affairs might be all right for the air transport companies, who used very large machines, but it seemed to put out of court the very light and small aeroplanes which might become popular among the poorer people.

No plans of aerodrome buildings had been shown by Squadron Leader Norman, but it seemed that finality had not yet been reached in regard to means of catering for heavy passenger traffic passing through.

Mr. DOWER: He was particularly interested in the descriptions of American aerodromes given in the course of the lecture, because his own inspections of aerodromes had been confined to the Continent, where the treatment of the various problems was extremely different from the American treatment; there were no runways, the type of planning which Squadron Leader Norman had in the main condemned had in the main been followed, but the buildings were distinctly finer architecturally, though perhaps there were some shortcomings from the point of view of efficiency. The only point on which he would cross swords with the lecturer—though perhaps even in that they did not really differ widely—was his apparent condemnation of the recreational use of aerodromes. He felt that a good deal of any commercial success that had been achieved at the bigger aerodromes had been based on their recreational use. Fine buildings such as those at the Tempelhof Airport of Berlin, attracted sight-seers; thousands of Berliners went there and used the restaurant, and passengers could spend their waiting time very much more comfortably there, in restaurants overlooking the field, than they could in the draughty hall at Croydon, where one could see nothing except a number of clocks. In this country at the moment the provision of aerodrome sites was perhaps even more important than the detailed planning of the aerodromes. It was impossible to emphasise too often that the quick and effective development of commercial aviation was essentially dependent on the provision of adequate ground work, and at the present stage the vital part of that ground work was that the town planning authorities should select and reserve at once the sites for the future aerodromes, rightly related to the big towns. The fact that they were so reserved would not prevent their use for agricultural or other open-space purposes until time was ripe for their development as aerodromes. The various safety factors rendered the selection of an aerodrome site one of the most difficult tasks in connection with town planning; therefore, in any town planning scheme the aerodrome site should be selected first, on aeronautical and other grounds, and the rest of the town planning should be developed, in the immediate neighbourhood at least, around the selected aerodrome site.

Mr. GORDON ENGLAND: It was clear that an enormous responsibility rested upon aerodrome consultants in the future. Such a consultant must be skilled in the selection of a suitable site from the aircraft point of view, he must possess an idealism in town planning, he must visualise the future commercial possibilities of aviation in order to make provision, around a particular aerodrome, for such commercial and industrial activities as would depend upon it, and at the same time, he must obviously provide something for the immediate present easily and cheaply. A very heavy responsibility indeed rested upon those who claimed to be aerodrome consultants, for their work would be of paramount importance in the future. Next, obviously, there must be civil engineers who could guard against serious errors being made in the exploitation of aerodrome sites—and, whilst not wishing to be regarded as entirely mundane, he suggested that the æsthetic consideration, which the architect would bring to bear in the development of these airports, should be very severely restricted at the beginning. When

he had seen Squadron Leader Norman's pictures of some of the magnificent buildings erected on aerodromes he had felt that they might constitute millstones around the neck of commercial aviation. Those buildings had to be paid for by someone, somehow and at some time, and if they gave undue rein to their enthusiasm for magnificent aerodromes and grand buildings they might cripple the commercial development of civil aviation very severely indeed. The interest on the capital invested in the aerodromes and buildings must be earned, of course, by the operating aircraft. One did not wish to see commercial aviation saddled with terrific overheads such as those with which the railways had saddled themselves, which would render its future development very difficult indeed and its adaptability to changing conditions almost impossible.

He was very glad to note the very natural and logical course which had been followed in the planning of the aerodrome and its surroundings at Akron. Assuming that the development of aircraft would follow normal lines for a considerable number of years, and that there was not an entire revolution in the form of aircraft, as in the direction of the autogiro, the aerodromes must be big open spaces providing easy approach and exit. It was perfectly logical, having provided these big open spaces, that they should be developed as the big lungs of our future cities, and that recreation grounds and other places of entertainment should be provided around them. The smoke problem would not arise, as it had done in the development of some other forms of transport.

He would have liked to have heard more about water sites, having regard to the possibilities of amphibians. There were a number of small lakes in Scotland which might well be used as aerodromes, and there was a good deal of marshy and boggy land in England which could not be used for any other purpose, but which might be developed for such work. Perhaps such aerodromes would be the cheapest form.

It had been shown quite clearly that the proper facilities for the comfort of passengers could be provided at practically no cost. Obviously the little shelters which could be run out to the aeroplanes were not expensive. He was afraid it was too often overlooked by the designers of aerodromes, and by the aircraft operators themselves, that the only reason for their existence as such was the conveyance of passengers, mails and goods, and that the passenger could be the most potent adverse influence in the whole thing. One could kick a package and it would not complain, but the passengers, if not treated properly, could be the very worst advertisements for aviation, and the industry should play up to them. It was most disastrous that passengers, when landing after their first flights, should be bundled out of the aeroplanes in bitterly cold weather, particularly if the journey had not been over smooth and they were not feeling too well. That sort of experience led them to resolve not to fly again. After all, aircraft passengers paid the highest rate for travel—and very rightly—and it was not unreasonable that they should expect the greatest luxury in return. He believed it was mainly thoughtlessness and a lack of imagination which had prevented the greater development of this aspect of air travel, and he was very glad that it had been emphasised by Squadron Leader Norman.

Flying Officer N. N. JACKAMAN: Commenting upon Squadron Leader Norman's reference to the provision of wireless masts on terminal buildings or hangars, or at any rate, on the aerodromes themselves, he asked if it were really advisable to provide these very tall masts on the aerodromes, bearing in mind that machines had to land at night or in thick weather. Further, he had heard that wireless experts did not like their masts situated on or near buildings, particularly when they were concerned with direction-finding, because such disposition of the masts affected the accuracy of direction-finding. As to the suggestion by Squadron Leader Norman that the buildings at Tempelhof might have been pushed more forward, apparently the main argument was that under present conditions there was a great deal of taxying and many tail skids were worn out.

That was perfectly true, because he personally had worn out three tail skids in the course of four visits there. But with the advent of tail wheels, that difficulty should not arise.

Discussing the Akron airport, he said it was surprising to find that there was a very steep hill right alongside the aerodrome, and he wondered if any marked down-draught was experienced. It appeared that a take-off in that direction, with the wind, of course, coming from that direction, would be very much affected.

He also asked if Squadron Leader Norman had any definite views concerning the provision of a single terminal building cum hangar. Did he regard it as a good idea to discharge passengers, then taxy into one door, out of the other, then pick up more passengers and take-off? As to the long doors, was there any mechanical device for opening them in the event of fire? Further, what was the horse-power of the motors required to lift each section, or alternatively, the whole length of a door.

With regard to the recreational side of aerodrome life, he was of opinion that it was very advisable to provide a tea garden or some attraction of that kind, and it should be situated preferably on the roof of the administration building, so that the people taking tea there could also watch the flying. Of course, as flying became more and more common, people would not wish to spend much time watching it, but for the time being they were interested.

Finally, he asked what length of time was occupied in conveying the passengers by means of canopies to the aeroplanes? Could two men operate them and convey the passengers to the aeroplanes in a few seconds, or was it necessary to have a whole squad of men engaged in this work, and were the passengers kept waiting for any length of time?

Mr. KEITH (a distinguished American engineer who had travelled extensively, both by night and day, on American and European air routes): He recalled Squadron Leader Norman's remark that on the picnic grounds adjoining the Akron aerodrome even gas stoves were provided, and said that that fact was characteristic of the efforts of the Americans to provide the maximum of comfort in connection with their air transport systems. He had noticed the difference as between America and Europe in the matter of the facility with which one could get to the airports from the cities. If one were in Chicago, for example, and wished to travel by aeroplane, one could find any number of points within the city from which one could get a bus to the airport. Here, however, so far as he knew, one had to go to the air line offices in the city to arrange to get to the airport. The accommodation inside the aerodrome buildings in Europe was good, but passengers did object to having to go out into the cold air or the rain to board an aeroplane, or when leaving it. Recently, when leaving Paris for Croydon, he had got a wetting on the way out to the plane. The provision of a canopy was a great help. In America one could go from New York to Los Angeles and would always be under cover. At Port Columbus the airport was outside the city, but the train stopped at the airport, and one could change from one means of transport to the other without leaving cover. A feature of American transport was that it was run on commercial lines, but yet those responsible tried to make it an individual business at the same time. If, for instance, a business man telephoned the air station to the effect that he wished to travel by a particular aeroplane, but that he could not reach the airport until five or ten minutes after the scheduled time for the aeroplane to leave, the transport company would arrange to delay the departure of the aeroplane for his benefit. If the transport companies would not do that sort of thing the American business man would not patronise them anything like so much as he did. It seemed that the business was a little more impersonal, or less individualistic, in Europe than in the States.

Dr. H. CHATLEY: He asked if Squadron Leader Norman had seen any instances in which provision was made for seaplanes to land on water alongside aerodromes for land machines. One could imagine that in future there would be many instances in which seaplane services would connect directly with aeroplane services, especially, of course, at coastal stations. An optimum layout for such cases does not appear to have been worked out.

Mr. L. A. WINGFIELD: There seemed to be a popular assumption that town planning schemes would produce airports, but he considered it much wiser to assume that it would not produce them, at any rate in the lifetime of the present generation, and that they would only be produced by private enterprise, which, in fact, had been responsible for the majority of them in this country. Having regard to the vital need for the rapid development of airports, the aircraft industry should not wait for the town planning authorities—who did not necessarily consider aircraft and air transport as such—but should develop the ports itself, and he suggested that it should seek legislation to assist that development. It was well known that other countries had adopted certain laws concerning airports, and had sought to regulate the heights of buildings within their immediate ambit. We in this country also should consider whether, in view of the importance of the proper development of airports, that development should be facilitated by legislation. In the early days of the development of railways, electricity supply and other services, it had been necessary to invade to a moderate extent private property rights, in the interests of the public service. That principle had been adopted so frequently that one need not make any excuse for mentioning it in connection with airport development. Of course, there had always been provision for compensation to private property owners, and there might be minor difficulties, of course, in trying to fix compensation for loss of air space, but some scale of compensation could be worked out.

Lieut.-Comdr. the Hon. J. M. SOUTHWELL: He suggested that the scheme most commonly adopted, whereby the aerodromes, circular or rectangular in shape, were entirely clear at the centres, the buildings being situated around the edges, was both wasteful of the area available and inefficient. One of the first essential principles in the layout of airports when they had to deal with a large amount of traffic—as they would have to do if they were to be made to pay—was to separate the points of arrival and departure, as was done at railway termini. Secondly, everything must be done to facilitate the rapid handling of traffic. One of the problems in this connection was the time occupied in taxying; the time spent in taxying on the ground was time lost, and if much taxying had to be done the machines would get into each other's way. Thirdly, all traffic arriving at an airport had to approach the main control building, and loading and unloading must take place under cover. He suggested that, in principle, the landing space at any aerodrome may be considered as a circle, and the best layout was an aerodrome with all the buildings constructed within a segment comprising about 60 degrees of the circle, the station building being as near as possible to the centre of the field. It might be thought that this would obstruct landing, but actually obstruction was reduced to the minimum when this layout was adopted, because there was still available for landing the greatest length of ground in any direction. Of course, the planning of runways would have to be considered, too, in siting the buildings; but, according to some of the plans shown by Squadron Leader Norman, that would be simple, as there was a large "V"-shaped space reaching to the centre of the aerodrome, at which point all the runways met. All the existing airports were large enough to provide a circle of 500 yards radius, and that was all that was required for a normal take-off and for landing, though that, of course, was governed by the airworthiness regulations. If the terminal building were situated almost at the centre, as suggested, departing aeroplanes could get away quickly, and arriving aeroplanes, having landed, would finish their run at a point somewhere near the

centre. Thus, the time wasted on the ground would be reduced to the minimum. The position of the buildings would naturally depend somewhat on the prevailing wind direction, but, whatever the direction of the wind and the weather conditions, one could always divide the aerodrome space into two zones, one for arrival and one for departure, except for the purpose of abnormal machines which required more than the normal run. The only aerodrome he knew of which approached this shape was that at Hanworth, which could quite definitely at any time be divided into departure and arrival zones, so that the safety of flying would be increased. Squadron Leader Norman had mentioned another, at Buffalo, where the buildings were concentrated within a right angle.

Commander COLSON: What facilities exist for getting from the American aerodromes to the cities, and how much time was occupied in that connection?

Mr. D. O. BUSTARD (Imperial Airways, Ltd.): The vast expanse of territory in North America which is scattered with small lakes, might well be selected as suitable country over which air companies could operate, provided the traffic warranted it, the larger lakes being used as ports, the others as emergency alighting points. In this connection he pointed out that Imperial Airways, Ltd., operated services of flying boats in Central Africa over country which, according to the map, seemed quite devoid of any suitable alighting points for this type of aircraft. Actually there were very many narrow lakes there, so small that they were not marked on the map, but quite large enough to enable large flying boats to alight. It would be interesting to know whether there were flying boat services in North America operating over similar ground. Some years ago, when travelling between Ottawa and Winnipeg, by train, he had noticed that most of the country through which he passed was dotted with small lakes, large enough to accommodate flying boats. Using one of these lakes as an airport would be quite inexpensive; the only equipment needed would be a control tower on the edge of the lake. Such stations could well be illuminated and used at night.

Flight Lieut. R. E. H. ALLEN: All wind indicators at aerodromes should indicate the force of the wind as well as the direction. He asked whether the system used in America for signalling from the control tower to the aircraft on the ground as to when they should leave, and so on, was similar to that used at Croydon. He was rather disappointed that Squadron Leader Norman had not exhibited a plan of the Croydon airport, in order that it could be compared with the American airports. With regard to aerodrome consultants, he suggested that we should soon arrive at a stage at which they would have to pass some sort of qualifying test before being allowed to practise. Finally, he protested, amid laughter, that a great deal had been said about the comfort of aircraft passengers; it was rather sad that this race was losing its hardiness.

Mr. T. L. PATERSON: Were the airports in America owned in most cases by the municipalities or by the transport companies, and particularly were any of them owned by the railway companies? The railway companies of this country had power to operate air services, but had not yet exercised them, and he wondered whether the railway companies in America had done so.

The CHAIRMAN: Does Squadron Leader Norman advocate the use of runways of the concrete or hard-core variety in this country and, if so, in what manner? Also, having provided an airport with runways, how would he suggest the air control and ground control should be organised there? Again, having regard to his great experience, particularly in America, how many movements of aircraft, in and out, per hour or per day, on the basis of day flying only, would be handled by the average airport with safety? His views on night lighting equipment would be valuable, particularly by reason of his experience in the United States, where there were nearly 20,000 miles of regular night flying routes. What facilities were there in America for dealing with fog, and were there special arrangements, from the navigation and landing point of view, made at the airports during

foggy weather? If so, it would be interesting to know what they were. Further, the Chairman asked how, in America, obstructions in the neighbourhood of the airports were dealt with.

Proposing a very hearty vote of thanks to Squadron Leader Norman for his lecture, in the preparation of which he had gone to tremendous trouble, the Chairman said that when the history of the development of civil aviation in this country came to be written, Squadron Leader Norman's name would be in the forefront, in view of his work in connection with ground organisation.

Reply to Discussion

Squadron Leader Norman, replying to the discussion, said that the problems arising in connection with the existence of black cotton soil were engaging the attention of British aircraft operators. The conditions prevailing in America were not so bad as where the real black cotton soil existed, but undoubtedly in many parts of that country the ground was unworkable during certain parts of the year, particularly in the spring, when the frost was coming out of the ground. That was the reason why there were so many runway aerodromes in America, and the problem of providing hard surface landing grounds had come to the fore. He considered that the provision of hard surfaced runways might be the solution to the problem in other countries.

With regard to the point made by Mr. McClure, that the runway system did not appear to be suitable for the ordinary type of light aircraft of the kind developed for private owners in this country, he said he believed that in most of the runway aerodromes it would be found that by landing slightly out of the axis of the runway one was able to land so nearly into the wind that there were no ill effects. In the course of the 6,000 or 7,000 miles he had flown in America, using a Puss Moth, he had used aerodromes of this type without any difficulty.

He agreed with Mr. Dower that the architecture of the buildings on European aerodromes was on the whole better than in America. Mr. Dower had taken him to task for saying that the recreational use of airports was unimportant. The truth was that he considered it most valuable for propaganda purposes, but he suggested in the lecture that it might be carried on at a building separate from the main traffic centre of the airport. He agreed that town planning was vitally important at the present time, and he would have liked to have said more about it, but the subject of the lecture was the airport itself.

With regard to the responsibility of aerodrome consultants, he emphasised that this responsibility was strongly appreciated by a small band of people who were studying these problems and struggling to equip themselves to deal with them. Unfortunately, they had to pay for their own education and the number of jobs going was not such as to render this very easy. He had stressed in the lecture the importance of economy and had pointed out the lessons in that connection. Newer buildings in America would no doubt be of much less flamboyant type than the older ones.

He would like to discuss the problems introduced by the autogiro, but they were so complicated as to warrant a whole paper. He did not pretend to know as much about seaplane stations as land aerodromes; the problems connected with them also should be treated separately.

Commenting on Flying Officer Jackaman's reference to wireless beacons, he suggested that if one landed at Croydon against an easterly or north-easterly wind one would find something painted red and white as one approached. That might answer the question. He had not investigated fully whether it was possible for a beacon of that type to be placed in the middle of the re-entrant wedge where the main road approached an airport, but he suggested that if correctly arranged there was space for a beacon of that type. It would be the

right place, because no aircraft would pass over it, and it would be in a true position near to the centre of the airport.

His point with regard to taxying was that it represented waste of time. As to the position of the aerodrome at Akron in relation to the hill alongside it, he said there was no doubt a down draught there, but the port was very big and he imagined that the problem was not a serious one.

The unit type of building he had described was very convincing when one saw it, and it might be a very good beginning on a number of airports, particularly where there were from the start a good many resident aeroplanes. He believed there was a mechanical device for winding up the canopy doors illustrated, which involved a man going up to the rafters. The motors used were of small h.p. As to the loading canopies, two men occupied about half a minute in running them out.

The airport at Port Columbus, U.S.A., was the property of the railway company, and had been specially developed in connection with the railway.

There were a number of examples of seaplane stations alongside aerodromes. New York had one at North Beach and another under construction at Floyd Bennett Field. No finality in design was apparent, and often the slipways were at the opposite side of the aerodrome to the buildings, and the seaplane base not really effective. He had seen places where amphibian services were operated from land aerodromes, particularly at San Francisco, where the machines landed on Oakland Airport at one side of the bay and used a floating type of slipway alongside the docks on the other.

He agreed with Mr. Wingfield that it would soon be necessary to secure legislation to assist airport development. One very important point was the regulation of the height of buildings. Further, he believed it would be necessary in the near future to secure powers for the compulsory acquisition of sites for traffic control stations and signal lights on recognised air routes.

As to the layout of airports, he agreed closely with many of the remarks made by Lieut. Commander Southwell. The separation of the arrival and departure zones was very important. At some airports in the States, particularly Pittsburg, the landing positions were marked by clear lines on the ground. He had worked out an ideal layout, which must be very similar to the one Mr. Southwell had discussed, having a 60° wedge. A more or less central position for the terminal building was desirable. There was no doubt that the Hanworth airport could be planned to fit in very well with a layout of the kind Lieut.-Commander Southwell had described.

The question put by Commander Colson, as to the time occupied in travelling from the airports to the cities they served in America, was very pertinent, because in some cases the distance from the airport to the city was tremendous. The New York municipal airport was about 29 miles from the centre of the city. On the other hand, there were some airports in close proximity to the cities, as, for example, those at Kansas City and Detroit. Generally speaking, the distance between the airports and cities was rather greater in America than in Europe, and the time occupied in travelling from one to the other usually longer.

The lecturer shared Flight Lieut. Allen's view that wind indicators ought to show the force of the wind as well as the direction. As to signalling, he said that on some airports lamps were used in the manner adopted at Croydon, on others there were fixed lamps, the illumination of which was worked from the control tower, and on some of the very large airports control was by flag. He agreed with the remarks made as to the desirability of aerodrome consultants demonstrating their qualifications—so long as he personally had not to sit for an examination. (Laughter.)

The majority of the American airports were municipally owned, a few were privately owned and one or two were owned by railway companies, one of the latter being that at Port Columbus, referred to by Mr. Keith.

Replying to the Chairman, he said he would not at the moment advocate hard surface runways in this country, at any rate until traffic became so heavy as to wear out the grass—and that situation would not arise for some time. The question of traffic control was too wide for him to deal with it fully at the moment. It was difficult to prophesy the maximum density of traffic which could be dealt with at a civil airport, but he imagined that about 150 machines per hour in each direction would represent saturation point. He had dealt to some extent with night lighting in the lecture, and there were some very interesting examples of different systems in America. The use of a single fixed floodlight impressed him as being the most interesting form he had seen. Special devices to assist landing in fog had been tried experimentally, based on wireless control of aircraft by beacons of the " A.N." type. He had seen a simple and effective method used in California. The control officer took his wireless microphone out on to the aerodrome on a long lead and, listening for the approaching aeroplane, told the pilot from minute to minute where he was in relation to the landing area. He had been quite impressed when one pilot guided in by this method had landed without any difficulty in foggy weather, whereas he himself had just experienced a very miserable half hour.

Finally, he said he did not think there was any legislation in America governing structures adjacent to airports.

CALCULATION OF THE MOTION OF AN AIRSHIP UNDER CERTAIN CONDITIONS

BY

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(R.38 MEMORIAL PRIZE PAPER, 1932)

Introductory

1. The work described below deals, in detail, with the methods whereby the motion of an airship can be calculated. The possible motions of an airship are affected by such factors as its stability, motion of controls, release of hydrogen, dropping of ballast, engine power available, and gustiness of the air. The methods to be described are capable of dealing with these effects either separately or combined in any arbitrary proportions.

The statement of the causes of any motion is, of course, independent of the calculation of the consequences and in general the authors were not free agents in the choice of examples. The opportunity for beginning the investigation came as a result of a request from the Court of Inquiry into the disaster to H.M. Airship R.101,* and the calculations consequently refer to that airship. The prescribed control movements, gusts, state of static balance and so forth which are dealt with were, in general, those laid down by the Court of Inquiry. Owing to the exigencies of the case, the calculations made for the Court had to be carried out at great speed and work on some of the cases was stopped as soon as it became evident that the results would not be of direct interest to the Court. Most of the results obtained are included in Appendix VI of the Report of the Court (1).

The investigations carried out for the Court of Inquiry were afterwards published for the Aeronautical Research Committee as R. & M. 1401 (2), and the authors wish at the outset to express their thanks to the Aeronautical Research Committee and to the Director of the National Physical Laboratory for permission to include the work in this paper.

Since the publishing of these Reports, further work has been done; cases have been worked out which are thought to be of general interest and some of the cases calculated for the Court of Inquiry have been extended; it is not claimed, however, that the cases worked out exhaust the possibilities.

2. The equations of motion of an airship can only be solved analytically, if the movements of the airship are so small as to cause no change in the values of the derivatives. Any finite changes in the motion of the ship alter the values of some of the derivatives and render the equations incapable of solution by ordinary methods. The method that has been adopted is that of step-by-step integration, where the values of the variables at the beginning of an interval of time are known and the increments in the variables are calculated from the equations of motion. The advantage of the method is that any arbitrary changes in the conditions can be adopted. For example, it was necessary in the work described to assume changes such as alteration of elevator setting, dropping of

* A list of references (shown in brackets in the text) is given at the end of the paper.

ballast, gusts, shutting down of engines, loss of gas from any gasbag, increase of drag of airship due to damage to the cover, and trapping of gas in the hull. The effects of any or all of these could be included provided the aerodynamic data were known for the attitude of the ship relative to the wind.

3. All the cases considered deal with the motion of the airship R.101 in a vertical plane. The aerodynamic characteristics were observed on a model of the airship in a wind tunnel and the results are given in R. & M. 1400 (3) of the Aeronautical Research Committee. From these results the corresponding full-scale values were calculated. It was necessary to measure the forces and moments due to translation separately from those due to rotation and these were used directly in the equations of motion, so that the form of the aerodynamic forces and moments is $X_\theta V^2$, $Z_\theta V^2$, $M_\theta V^2$ for the translational terms and $X_q Vq$, $Z_q Vq$ and $M_q Vq$ for rotation.

Axes

4. The usual system of axes was adopted and is shown in Fig. 1. The origin has been taken at the centre of buoyancy of the airship instead of at the centre of gravity and it has been assumed fixed in the airship. This simplified the calculations considerably as all the aerodynamic characteristics were measured

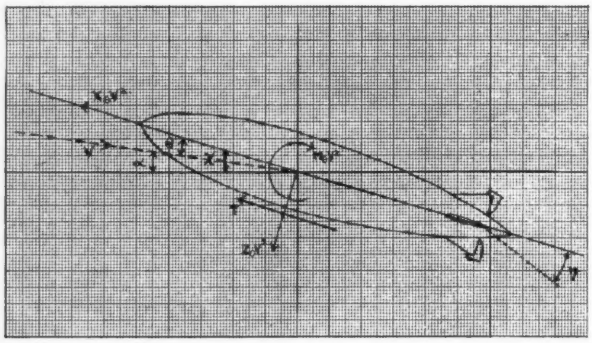


FIG. 1.

relative to the C.B. In point of fact, the C.G. was about 20 feet below the C.B., but any errors introduced by the simplification were small. Thus the inaccuracy in the moments due to the drag and to the propeller thrust was neglected, since these two forces approximated to a couple.

Symbols

5. The following symbols were used:—

V = velocity of the C.B. of the airship (the origin of co-ordinates) relative to the air.

u, w = longitudinal and transverse components of V.

q = angular velocity of the airship in pitch.

χ = inclination of the longitudinal axis to the horizontal, positive when the nose is up.

θ = inclination of the longitudinal axis to the relative wind (angle of pitch), positive when the wind is below the nose.

α = inclination of the flight path to the horizontal in still air, positive when the airship is climbing.

W = general heaviness of the airship (excluding P), assumed to act through the C.B.
P = heaviness due to specified loss of gas.
Pk = moment of P about the C.B. when the airship is horizontal.
$-M \sin \chi$ = static moment of airship.
T = total airscrew thrust.
Th = moment of airscrew thrust about the C.B.
m = mass of airship.
m_1, m_2 = virtual masses of airship longitudinally and transversely.
B_1 = virtual moment of inertia of the airship about the axis of pitch.
X_θ, Z_θ, M_θ = forces and moment due to translation at unit speed.
X_q, Z_q, M_q = forces and moment due to rotation, at unit translational speed and unit angular velocity.
ξ, ζ = horizontal and vertical displacement of C.B.
η = elevator angle, positive downward.

In the calculations which involved a gust, certain modifications were necessary, and symbols were introduced replacing those above in some cases:—

V' = velocity of the C.B. relative to the air, during the gust.
θ' = inclination of the longitudinal axis to the relative wind during the gust.
u', w' = longitudinal and transverse components of V'.
u_o, w_o = horizontal and vertical components added to the velocity of the natural wind during the gust.

Equations of Motion

6. The equations of motion of the airship are as follows:—

$$\left.\begin{aligned} m_1\dot{u} &= X_\theta V^2 + T - (W+P)\sin\chi + X_q V q - mwq \\ m_2\dot{w} &= Z_\theta V^2 + (W+P)\cos\chi + Z_q V q + muq \\ B_1\dot{q} &= M_\theta V^2 - M\sin\chi + Pk\cos\chi + M_q V q + Th \end{aligned}\right\}$$

Certain of the quantities are interrelated according to the equations

$$\begin{aligned} \dot{\chi} &= q \\ \chi &= \theta + \alpha \\ \tan\theta &= w/u \\ V &= u\sec\theta \\ \dot{\xi} &= V\cos\alpha \\ \dot{\zeta} &= -V\sin\alpha \end{aligned}$$

and for calculations during a gust

$$\left.\begin{aligned} u' &= u + u_o\cos\chi + w_o\sin\chi \\ w' &= w + u_o\sin\chi - w_o\cos\chi \\ \tan\theta' &= w'/u',\ V' = u'\sec\theta'. \end{aligned}\right\}$$

Units

7. The units employed were tons-foot-second units, except for the terms involving X_θ, Z_θ, M_θ. The values of these quantities were originally calculated for the Court of Inquiry in the form of tons and tons-feet for a relative wind speed of one knot; and for expediency were retained in this form in the present calculations. Consequently the coefficients X_θ, Z_θ and M_θ had to be multiplied by the square of the wind speed in knots, whereas in all other parts of the work the wind speed was in feet per second.

Values of the Aerodynamic Quantities

8. X_θ, Z_θ, M_θ.—The values of X_θ, Z_θ and M_θ over the range required are

given in Figs. 2 and 3. Experimental data were asked for over a range of incidence from $-40°$ (wind above the nose) to $+20°$ (wind below the nose). The calculations have shown that large negative angles of incidence were not required, but that the range might have been extended with advantage to a greater positive angle. It has been necessary in one case to extrapolate beyond $+20°$ incidence; this could be done with a fair degree of certainty as the curves for X_θ, Z_θ and M_θ are nearly symmetrical.

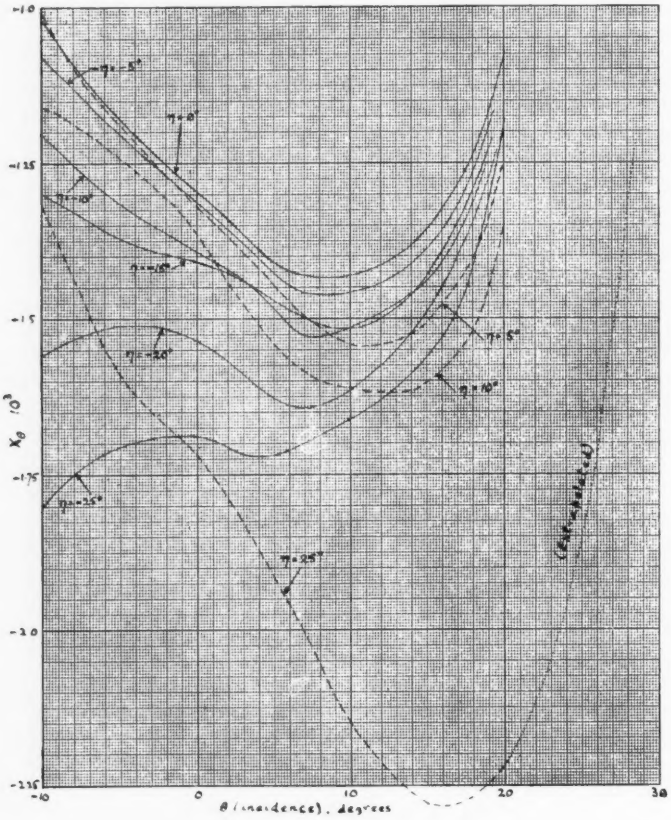


FIG. 2.
Values of X_θ.

9. X_q, Z_q *and* M_q.—As the work covered a large range of values of V, the terms due to rotation were taken to be of the form X_qVq, Z_qVq and M_qVq, the first two in tons and the third in tons-feet when V is in feet per second and q in radians per second.

M_q was the only rotary derivative which was measured. This was done in a wind tunnel over a range of incidence from 0° to 40°; it was assumed to be symmetrical about the zero angle of pitch. Z_q was calculated from M_q by

measuring the latter on the model with and without fins and elevators. The difference is the part of M_q " due to fins and elevators," and by assuming this to act at the C.P. of the stabilising surfaces, a value of Z_q " due to fins and elevators " is found, which is the chief component of Z_q. The accepted values of M_q and Z_q are given in Table I.

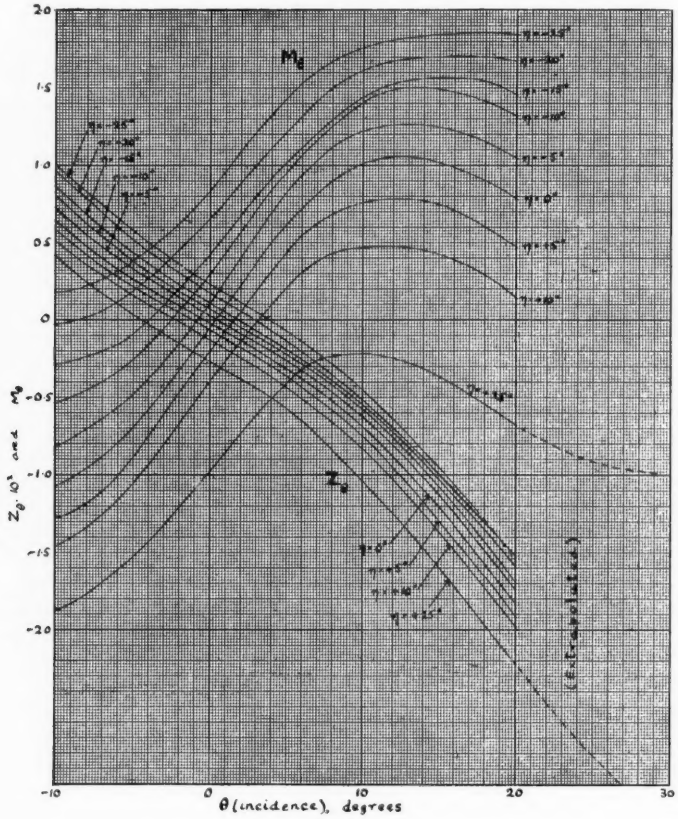


FIG. 3.
Values of Z_θ and M_θ.

TABLE I.

VALUES OF M_q AND Z_q.

θ	0	5°	10°	15°	20°	25°
M_q	−1490	−1580	−1660	−1760	−1960	−2290
Z_q	−4·24	−4·52	−4·76	−5·14	−5·70	−6·74

There are no practical data from which X_q can be determined. It can, however, be shown that for a prolate spheroid (4) the value of X_qV is nearly equal to mw; hence it has been assumed that $(X_qV - mw)$, which is the form in which X_q appears, can be neglected.

Mass and Virtual Mass

10. *Mass.*—The mass m of the airship has been taken to be the mass of the air displaced together with the mass of any general heaviness and any increase of mass due to loss of lift by leakage of gas. The value is the weight in tons divided by g. The mass of air displaced by the ship is 6.75 units.

Moment of Inertia.—The moment of inertia of the ship about the transverse axis was assumed to be 2.02×10^5 units. This figure was derived from the figure, given by the Royal Airship Works, Cardington, of 1.64×10^5 units for the structure alone, making an allowance for the moment of inertia of the air and hydrogen in the envelope.

11. *Virtual Mass.*—In any discussion of the accelerated motion of an airship the effects of virtual mass are of importance. The acceleration of a body in a fluid is dependent on the disturbances set up in the fluid by the body. It has been shown (5) that, if the accelerations are small, the effect may be represented by additions to the mass of the body. As these virtual mass effects are of the nature of acceleration terms, the additions must be made to the masses and moment of inertia on the left hand side of the equations of motion, but they must not be included in any of the terms on the right hand side of the equations, such as muq, nor must corrections for virtual mass be made for the parts of the mass due to the heaviness of the ship.

The values of the virtual masses along the longitudinal and transverse axes are not known with any certainty. Following the results of R. & M. 613 (6), allowance has been made by increasing the mass for the longitudinal equation by 5 per cent., and that for the transverse equation by 100 per cent. An addition of 75 per cent. has been made to allow for the virtual moment of inertia. After a few cases had been worked out, it was found sufficiently accurate to take the values of m_1, m_2 and B_1 constant throughout any case, as the differences due to leakage of gas would be very small for the few minutes under consideration. The values assumed for the greater part of the work were

$$m_1 = 7.5, \quad m_2 = 13.9, \quad B_1 = 3.81 \times 10^5, \quad m = 7.15.$$

Later, justification was provided for the neglect of changes in these quantities. Case M was recalculated, as Case S, with identical conditions of heaviness, elevator movements, gust and so forth, as obtained in Case M, but with very different values of m_2 and B_1, and the results were nearly the same. The comparison is considered in greater detail below.

Airscrew Thrust

12. The variation of airscrew thrust with speed is given in Table II. The values were plotted and the required value at any particular speed was read off the curve. The thrust was calculated on a basis of constant b.h.p.; the method by which it was obtained is described in Appendix I of R. & M. 1400 (3). The thrust has been assumed to act parallel to the longitudinal axis of the ship for all attitudes of the ship and no allowance has been made for any lateral forces on the airscrews. The mean thrust was taken 60ft. below the longitudinal axis.

TABLE II.

VALUES OF AIRSCREW THRUST.

V ft./sec.	40	50	60	70	80	90	100
T tons	6.01	5.63	5.19	4.80	4.42	4.00	3.56

The term " engines shut down " has been used to indicate a change from full thrust to zero thrust, and the change has been assumed abrupt in all cases. Zero thrust would occur if the engines were shut down to about half the full revolutions at cruising speed. The engines have been assumed to be giving

full airscrew thrust all the time, except when " shut down "; this applies to all the cases considered with one exception, which deals with the motion of the ship when the airscrews are giving half thrust only.

Heaviness

13. The heaviness of the ship has been divided into two parts:—

(*a*) *General Heaviness*, (W) due to ballast or to general loss of gas, or to rain water picked up during the flight. W may be altered by dropping ballast. The general heaviness, W, has always been assumed to act through the origin of co-ordinates.

(*b*) *Particular Heaviness*, (P) due to loss of lift caused by leakage of gas from a specified gasbag, acting at a definite distance (k) from the origin. In most cases, k has been taken to be the mean distance of the particular gasbag from the C.B. In one case it has been assumed that some of the escaped gas has been trapped in the hull and moves to the tail when the nose of the airship is tilted down. To account for this, an appropriate quantity (K) was added to the right hand side of the moments equation. The effects of the trapped gas on the position of the centre of gravity were neglected.

Damage to Cover

14. Among the effects which the N.P.L. was asked to consider was that due to damage to the outer envelope near the nose; in most of the later cases worked out for the Court of Inquiry, this was done by assuming an increase in the drag. This would, of course, reduce the speed of the ship, thereby increasing the effect of any heaviness at the nose compared with the aerodynamic effects. The allowance made for increase of drag was the addition of 0.002 to the numerical value of X_ϕ. No alterations were made to the values of Z_θ and M_θ, as experiments on airship models with artificially increased drag (7) have shown that there are no appreciable changes in the transverse force and moment.

Gust

15. When an airship encounters a gust, the equations of motion must be modified by using the additional equations of §6. As there is no information as to the behaviour of an airship when it is struck by a gust which varies along the length of the ship, or as to the impulsive changes in the aerodynamic characteristics due to sudden changes in the direction of the wind, the form of gust that has been assumed is one equivalent to an instantaneous increase in the horizontal and vertical wind velocities, acting along the whole length of the ship for the duration of the gust. V must now be replaced in the three equations of motion by V', the relative wind speed during the gust. χ remains unaltered, but the angle of incidence, at which the force and moment coefficients must be read off the curves, now becomes $\theta' = \tan^{-1} w'/u'$, where u' and w' are the wind velocities along the axes and are evaluated from the additional equations. V represents the velocity of the airship relative to the ground, assuming the ship to be flying in still air before encountering the gust. The effects of a steady velocity in the natural wind, on which the gust is superposed, can be included by adding suitable quantities to the final results. $\theta = \tan^{-1} w/u$ is still required for the determination of a, as the loss of height was calculated from V and a.

Solution of the Equations

16. The equations were solved by step-by-step methods of integration. The values of all the variables are known at the beginning of a particular step and the variations of these quantities made it easy, in most instances, to estimate mean values of u, w, q, χ and θ for the interval chosen. A mean value of V was calculated from $V = u \sec \theta$. T was read off the thrust curve for the mean

value of V; and X_θ, Z_θ, M_θ, M_q and Z_q taken from the curves at the appropriate θ. The values of the quantities on the right hand side of the equations of motion were then calculated and the increments $m_1\dot{u} \cdot \delta t$, $m_2\dot{w} \cdot \delta t$, $B_1\dot{q} \cdot \delta t$ obtained. From these the values of u, w and q at the end of the interval were found by adding $\dot{u} \cdot \delta t$, $\dot{w} \cdot \delta t$, $\dot{q} \cdot \delta t$ respectively to the values at the commencement of the interval. From the results it was obvious whether or not correct mean values had been chosen. If the mean values were seriously in error, it was necessary to recalculate the step with new mean values. In practice, the only variable which caused much trouble was q in the M_qVq term. It was found that the best procedure was to estimate u, χ, θ, and to obtain the quantities on the right hand side of the q equation, except M_qVq; then to determine q by trial to give a correct mean value. This was possible as the increments of the other variables are not sensitive to small errors in q. The mean χ could be estimated with sufficient accuracy from the first approximation to the value of q. Having determined q accurately, the q terms in $m_2\dot{w}$ and the correct increment $\delta\chi$ were found.

17. The first steps were calculated by using small intervals of time, usually one-tenth of a second, and small intervals were necessary also when there were violent changes in the conditions. The intervals varied from one-tenth of a second to ten seconds, the long intervals being used only when the airship had settled down on a steady flight path. As the mass and the inertia of the airship were large, it was found, after gaining some experience of the method, that one-second or two-second intervals could be used for most of the work, even when dealing with gusts.

Specimen Page

18. The scheme of work employed in the calculations is shown in Fig. 4. In the left half of each column are given the values of the quantities at the commencement of the interval, and in the right half the assumed mean values for the interval. The page has two columns illustrating the greater part of the work and two columns including gust terms. The terms enclosed in brackets are mean values obtained from the initial and final values. They were not necessary for the calculation of the step, but were required for the evaluation of ξ and ζ.

Accuracy of Work

19. Twenty-inch slide rules were used throughout, as three significant figures only were necessary for most of the work; the moment equation was the only one where four figures were sometimes required. Small errors due to over-estimating or under-estimating the mean values were unimportant except for q, and they were eliminated in the case of q by the order of procedure adopted in working out the step. The small errors were not cumulative as the aerodynamic quantities involved are in the nature of damping factors. For example, if too large a mean value of w be taken, this will make θ too high and this, in turn, will give a value of $Z_\theta V^2$ which will tend to make the increment δw too small. Errors introduced by choosing intervals that were too large showed themselves in fluctuations in the values of the increments, these being alternately too large and too small. Errors in χ, ξ and ζ were cumulative, but they were immediately obvious if they were large.

20. It was found that the final motion of the ship in each case was not very dependent on the initial conditions, as the airship tended to settle down on a steady flight path. This is well shown in Case N (Fig. 24) which was worked out for a gust of 12 seconds' duration and also for the same gust of 15 seconds' duration. In quite a short time the curves become nearly coincident, illustrating again that the aerodynamic quantities are in the nature of damping factors. It

η	+7°			← Gust → +6°		+5·5°
t	6	8		10	11	12
δt	2	2		1	1	
V (ft./sec.)	73·77	73·30		72·73	72·03	
V (knots)	43·69	43·43				
u	74·00 73·75	73·50 73·28		73·07 72·70	72·33 71·98	71·63
w	1·75	1·76		1·78	2·45	3·02
q	−·01305 −·01327	−·01349 −·01341		−·01332 −·01582	−·01831 −·01977	−·02123
$\chi = \theta + \alpha$	1·98 1·22	0·46 −0·31		−1·08 −1·54	−1·99 −2·56	−3·12
$\theta = \tan^{-1} w/u$	1·35 1·36	1·37 1·38		1·39 (1·67)	1·95 (2·19)	2·42
α	0·63 (−0·14)	−0·91 (−1·69)		−2·47 (−3·20)	−3·94 (−4·74)	−5·54
P	6·23	6·30		6·35	6·38	
Pk = 250 P	1558	1575		1587	1596	
V_q (V'_q)	−·979	−·983		−1·466	−1·816	
u_q (u'_q)	−·979	−·983		−1·460	−1·810	
Gust Terms: V′ (ft./sec.)				92·81	91·88	
Gust Terms: V′ (knots)				55·00	54·43	
Gust Terms: $u' = u + 20\cos\chi + 10\sin\chi$				92·88 92·43	91·97 91·52	91·06
Gust Terms: $w' = w + 20\sin\chi - 10\cos\chi$				−8·60	−8·24	−8·05
Gust Terms: $\theta' = \tan^{-1} w'/u'$				−5·29 −5·21	−5·13 −5·09	−5·05
$X_0 V^2$	−6·40	−6·33		−9·61	−9·46	
T	4·65	4·68		3·90	3·94	
$-P\sin\chi$	−0·13	+0·03		0·17	0·28	
$m_1\dot{u} = 7{\cdot}5\dot{u}$	−1·88	−1·62		−5·54	−5·24	
$Z_0 V^2$	−3·23	−3·21		6·65	6·26	
$P\cos\chi$	6·23	6·30		6·35	6·37	
$Z_q V_q$	4·16	4·18		6·65	8·22	
$mu_q = 7{\cdot}25 u_q$	−7·09	−7·12		−10·59	−13·10	
$m_2\dot{w} = 13{\cdot}5\dot{w}$	0·07	0·15		9·06	7·75	
$M_0 V^2$	−172	−168		−2832	−2733	
Th = 60T	279	281		234	236	
4300 sinχ	−92	+23		116	192	
$-Pk\cos\chi$	−1558	−1575		−1586	−1595	
$M_q V_q$	1466	1468		2322	2878	
$B_1\dot{q} = 3{\cdot}5.10^5\dot{q}$	−77	+29		−1746	−1022	
$\dot{u}\delta t = \delta u$	−·50	−·43		−·74	−·70	
$\dot{w}\delta t = \delta w$	·01	·02		·67	·57	
$\dot{q}\delta t = \delta q$	−·00044	+·00017		−·00499	−·00292	
$57{\cdot}3 q\delta t = \delta\chi$	−1·52	−1·54		−0·91	−1·13	
$X_0 - 0{\cdot}200.10^3$	$-{\cdot}335.10^{-2}$	$-{\cdot}335.10^{-2}$		$-{\cdot}318.10^{-2}$	$-{\cdot}319.10^{-2}$	
Z_0	$-{\cdot}169.10^{-2}$	$-{\cdot}170.10^{-2}$		$+{\cdot}220.10^{-2}$	$\cdot 211.10^{-2}$	
M_0	−·090	−·089		−·936	−·921	
M_q	−1495	−1495		−1585	−1585	
Z_q	−4·25	−4·25		−4·53	−4·53	
$\delta\xi = V\cos\alpha\delta t$	147	146		73	72	
$\delta\zeta = -V\sin\alpha\delta t$	0·4	4·3		4·1	6·0	
ξ	449	596		742	815	887
ζ	−20·2	−19·8		−15·5	−11·4	−5·4
$\xi' = \xi - 40t$	209	276		342	375	407

FIG. 4.
Specimen page.

is also demonstrated by a comparison of Cases M and M_1 (Figs. 21, 23). Owing to the urgency of the work a simplification of the treatment of the gust was tried, u' being taken equal to $u+20$ and Case M_1 is the result. Subsequently, the error was discovered to be appreciable, especially in the u term and the case was worked out again (Case M) making proper allowance for the gust. The curves for Case M_1a are comparable with those for Case M.

21. It is difficult to estimate the absolute accuracy of the work, owing to uncertainties in some of the quantities employed. It was thought at first that the results would be very dependent on the values chosen for the virtual mass. As stated above in §11, a comparison of Cases M and S, which are identical but for m_2 and B_1, shows that considerable latitude is possible in the choice of these two quantities; and there is little difference after the immediate effects of sudden changes have passed. In the two cases, the ship very quickly settles down on the same path. It may be assumed that the order of the results and the form of the curves are correct. In some places there are unexpected kinks in the curves. These can be traced to sudden changes in the conditions, such as cessation of elevator movement. Other changes, especially in the q curves, can be traced to an irregularity in the spacing of the experimental curves for M_θ, where the moment curve for 10° up elevator is very close to that for 15° up elevator. This peculiarity is observable in the q curve for Case C. The unevenness in the spacing of the moment curve is, in all probability, due to observational error in the setting of the elevators during the experiments on the model airship.

22. Scale effect has been neglected in the calculation of the data for the actual ship from results obtained for the model. The model data have been assumed to be of the form $\rho k V^2 l^2$ for forces and $\rho k V^2 l^3$ for moments, where l is a linear dimension, and the values for full scale deduced therefrom.

Equilibrium of the Airship on Inclined Paths

23. Judged by the usual criterion of stability of an airship, the R.101 was at least as stable as the majority of modern airships, and her stability increased with angle of pitch. Of course, the airship is only in equilibrium on a horizontal path if she is flying at a small angle of pitch unless there are some extraneous forces acting, such as nose heaviness, to balance the dynamic lift and to give a moment sufficient to counteract the aerodynamic pitching moment. Evidence was laid before the Court of Inquiry to show that the R.101 could maintain height with nose heaviness, provided this did not exceed a certain amount depending on its point of application. If the airship had four tons general heaviness and began to lose gas from, say, gasbag 5, it could support 8.3 tons loss of lift out of the possible 14.4 tons before beginning to lose height; but if four tons of forward ballast were dropped it could maintain height with 12.4 tons loss of lift from that gasbag. The limiting values of the loss of lift from various forward gasbags are given in Table III for the ship: (*a*) With four tons general heaviness in addition to the nose heaviness; (*b*) for the same conditions after dropping four tons of forward ballast, giving a pitching moment of 700 tons-ft. Blanks in the table for any gasbag indicate that the airship could lose all the gas from that gasbag before reaching the limiting position.

TABLE III.

LIMITING LOSS OF LIFT FROM ANY FORWARD GASBAG FOR WHICH THE AIRSHIP CAN MAINTAIN HEIGHT.

Gasbag	1	2	3	4	5	6	7	8
k feet	319	291	248	200	152	106	64	21
Total lift (tons) ...	0.60	3.54	9.46	12.65	14.40	15.07	14.53	14.45
Limiting loss of lift (*a*)	—	—	7.35	7.85	8.30	8.80	9.15	9.45
,, ,, (*b*)	—	—	—	11.75	12.45	13.10	13.50	13.70

(*a*) Four tons general heaviness in addition to the specified loss.
(*b*) After dropping four tons of forward ballast (700 tons-ft.).

If the airship, damaged near the nose, continued to lose gas beyond these limiting amounts, it would be impossible for her to remain in equilibrium on a horizontal path with the assumed thrust and she would then begin to lose height. The airship would still be stable, but now on an inclined path instead of a horizontal one, losing height steadily, the angle of descent and the inclination of the axis to the horizontal depending on the elevator setting, and the amount of gas lost.

24. The equations of equilibrium may be written

$$X_\theta V^2 + T = (P + W) \sin \chi$$
$$Z_\theta V^2 = -(P + W) \cos \chi$$
$$Pk \cos \chi - M_\theta V^2 + M \sin \chi - Th = 0$$

whence, eliminating V^2 and T, may be obtained the relation

$$(M_\theta - hX_\theta)/Z_\theta = -Pk/(P + W) - \{ M/(P + W) - h \} \tan \chi.$$

If the function $(M_\theta - hX_\theta)/Z_\theta$ is plotted against θ for various elevator settings (η), the family of curves may be used for solving the equations of equilibrium graphically. Such a method is outlined in R. & M. 1400 (3), to give the attitude of the airship for a definite variation of P for fixed values of k, W and a. Application of this method gives the speed, attitude and flight path of the airship in the equilibrium states corresponding to the cases worked out by step-by-step methods. The values obtained by the latter method should approximate to these final values some time after the conditions have become steady.

25. In order to show how the variables approach the limiting equilibrium conditions, the results for Cases *A*, *B*, *C*, *D* and *E* are given in Table IV. All these cases deal with gasbag 5, for which $k = 152$. The ultimate values of the variables V, u, w, θ, α and χ are given for the five cases. The ultimate values for Cases *A* and *D* are necessarily the same, as in both cases the elevators are 5° up; in Case *B*, the elevators are 15° up; in Case *C*, 25° up; and in Case *E* the elevators are amidships. The values of the same variables and also $q = \dot{\chi}$ are given for the five cases at $t = 180$ sec. and they are given for Cases *A*, *B* and *C* at $t = 300$ sec.; Cases *D* and *E* were not carried so far.

TABLE IV.

VALUES OF u, w, ETC., FOR CASES *A*, *B*, *C*, *D*, *E*.

IV*a*. $t = 180$, $P = 11.0$, $k = 152$.

Case	η°	V ft./sec.	u	w	θ°	α°	χ°	$q = \dot{\chi}$ rad./sec.
A	−5	67·5	65·8	15·1	12·9	−2·3	10·6	−0·0012
B	−15	62·1	60·1	16·1	15·1	−1·1	14·0	−0·0022
C	−25	58·0	55·5	16·8	16·8	−0·2	16·6	−0·0033
D	−5	67·4	65·5	15·3	13·1	−4·1	9·0	−0·0003
E	0	71·9	70·5	14·1	11·3	−3·5	7·8	−0·0007

IV*b*. $t = 300$, $P = 13.0$, $k = 152$.

Case	η°	V	u	w	θ°	α°	χ°	$q = \dot{\chi}$
A	−5	70·3	68·2	16·4	13·5	−6·4	7·1	−0·0001
B	−15	65·1	62·6	17·8	15·8	−6·4	9·4	−0·0002
C	−25	61·2	58·2	18·5	17·6	−6·7	10·9	−0·0001

IV*c*. FINAL EQUILIBRIUM VALUES. $P = 14.4$, $k = 152$.

Case	η°	V	u	w	θ°	α°	χ°	$q = \dot{\chi}$
A, *D*	−5	73·6	71·2	17·2	13·5	−7·3	6·2	0
B	−15	67·5	64·9	18·7	16·1	−7·8	8·3	0
C	−25	63·5	60·4	19·6	18·0	−8·3	9·7	0
E	0	77·5	75·8	16·0	11·9	−7·0	4·9	0

There are two things to be borne in mind when considering the values: First, that at $t=180$ sec. the loss of lift is only 11.0 tons, and at $t=300$ sec. the loss of lift is 13.0 tons against the final value of 14.4 for P; secondly, that at $t=180$ sec. the conditions, apart from the continuous change in P, have only been constant for a comparatively short time—for example, in Case C the elevator movements do not cease until $t=125$ sec.—and consequently the ship is only beginning to settle down to a steady state.

The results obtained from the step-by-step calculations bear out those obtained from equilibrium considerations; the latter, however, give no direct indication of the time the airship would take to settle down on the steady path after a disturbance, whereas the former results give the complete history of the case. The general tendency of the ship to settle down on a steady path gives a vindication of her stability.

General Discussion of Results

26. *Case Letters.*—The letters used in R. & M. 1401 (2) for defining the various cases have been retained in this paper to avoid confusion, though some of the cases have been extended since the publication of that report and cases worked out additional to those submitted to the Court of Inquiry.

27. *Figures.*—Two figures are given for each case, one showing the changes in u, w, q, θ, α and χ with time; the second giving the height loss plotted against time in some cases, and in others plotted as a flight path when flying against a head wind. In the second figures, short lines have been drawn to show the attitude of the ship, the numbers representing degrees of inclination to the horizontal; the lengths of the lines are not indicative of the length of the ship.

28. *Initial Conditions.*—In the first cases calculated, the initial conditions were determined from the limiting conditions of equilibrium on a horizontal path. In the later ones, the initial conditions assumed were somewhat arbitrary, and in some cases, such as when the ship is flying horizontally with her nose 5° down, they were chosen without any regard as to how the ship had arrived at that attitude. The following considerations are given to show how the initial conditions for Cases L to P were decided upon. In gusty weather the ship would experience changes of height of 200ft. or so on each side of the mean flight path and, to correct these fluctuations, the height coxswain would make elevator movements of anything up to 8° or 10°. Generally speaking, the initial conditions chosen approximated to those which would obtain near the topmost point of an oscillation. The exact justification was not considered necessary in each case, as the airship quickly responded to changes in the conditions and very soon settled down on a path not very dependent on the initial conditions. The actual initial conditions proper to each case are given under the discussion of that case.

29. *Elevator Movements.*—The elevator settings are arbitrary, but, in general, an attempt has been made to give to the elevators movements similar to those which would be made by the height coxswain. The maximum rate of movement was stated to be 1° per second and this has been assumed in all cases where the elevators are put up rapidly. Occasionally, in accordance with the requirements of the Court of Inquiry, movements of the elevators have been presumed to be carried to the extreme up position, though it is obvious that they would be eased in actual flight.

30. *Loss of Gas.*—In all the discussions of particular cases, the expression "*loss of gas*" *has been used to denote* "*loss of lift by leakage of gas.*"

Large pitching moments due to the complete deflation of any particular gasbag were obtainable from gasbags 4 and 5 ($Pk=2{,}530$ and 2,190 tons-ft. respectively). Gasbag 5 was selected for the earlier cases as the possible loss of lift (14.4 tons) from it was greater than that from gasbag 4 (12.65 tons). When a very large moment was required to cause a disturbance without great

loss of lift, gasbag 3 was chosen, for which the maximum loss is 9.46 tons with a pitching moment of 2,340 tons-ft. The pitching moments due to the complete deflation of gasbags 1 or 2 near the nose could be balanced by the airship without loss of height.

31. *Heaviness.*—The first effect of heaviness of the ship is to pull her down, increasing w positively (downward). This increases the angle of incidence θ. The effect of an increase of θ is threefold; there results a dynamic lift which tends to balance the heaviness, an upward pitching moment which tends to counteract any nose heaviness, and an increase of drag which causes the speed of the ship to fall. Opposed to this last effect is the fact that the ship is losing height and therefore tends to increase her speed. The effects are all interdependent; but the process usually goes on until the aerodynamic pitching moment balances the moment due to nose heaviness. The general trend is demonstrated by the fact that the ship tends to settle down with her nose well above the horizontal in all cases where nose heaviness is specified and where the gross heaviness is greater than the maximum dynamic lift acting in horizontal flight.

Nose Heaviness: Effect of Elevator Setting

32. *Cases A, B, C.*—Ship 12 tons heavy; 4 tons general heaviness ($W=4$), 8 tons loss of gas from gasbag 5 at $t=0$ ($P=8$, $k=152$). Leakage of 1 ton/min. of gas from gasbag 5.

Initial conditions:—

$$V=71.3 \text{ ft./sec.}=42.2 \text{ knots}, \quad q=0,$$
$$\chi=\theta=9.8^\circ, \quad \alpha=0^\circ, \quad \eta=+1.5^\circ \text{ (down)}.$$

At $t=90$ secs., elevators are moved to $\eta=+1^\circ$ (down).

At $t=100$ secs., elevators are moved to 0° and then put up 1°/sec.

Case A.—Elevators stopped at 5° up.

Case B.—Elevators stopped at 15° up.

Case C.—Elevators stopped at 25° up.

33. The curves for these three cases are given in the same figures, as the conditions are identical except for the angle at which the elevators are stopped. The ship is very nearly in equilibrium at the start, flying on a horizontal path, but increasing forward heaviness is soon felt, causing the nose to drop slightly, and α becomes negative; the ship experiences a height loss of 100 feet in 100 seconds. The elevators are set amidships at $t=100$ and are then put up at the rate of 1° per sec. to 5°, 15° and 25° in the three cases. The curves for Cases *A*, *B* and *C* are very similar, the effects of the elevators being more marked, the greater the elevator angle. The immediate effect of up elevators is to raise the nose, χ increasing, and to cause the ship to climb, α becoming positive. θ, the angle of incidence, increases, and this augments the drag. The increased drag, combined with the gain of potential energy due to the ship gaining height, accounts for the fall in u. In each case, u decreases to a minimum and then rises and will continue to increase until it attains the limiting value given in Table IV (§25).

The angular velocity increases to a maximum, falls, becomes negative, then slowly approaches zero, being practically constant and very small after $t=250$. The peculiarity in the q curve in Case *C*, $\eta=-25^\circ$, has been mentioned above (§21) as being probably attributable to observational error in the experiments on the model of the airship.

The inclination χ of the ship to the horizontal increases to a maximum in each case (12.4° for $\eta=-5^\circ$, 17° for $\eta=-15^\circ$ and 20.6° for $\eta=-25^\circ$) after which it falls rapidly at first, then more gradually as the ship settles. At $t=300$, the nose is 7°, 9° and 11° above the horizontal in the three cases.

As the elevators are put up, the airship continues to lose height at first, falling to 135 feet below her initial height before she begins to climb. With 5° up elevators she only regains a few feet of her lost height before she goes on her

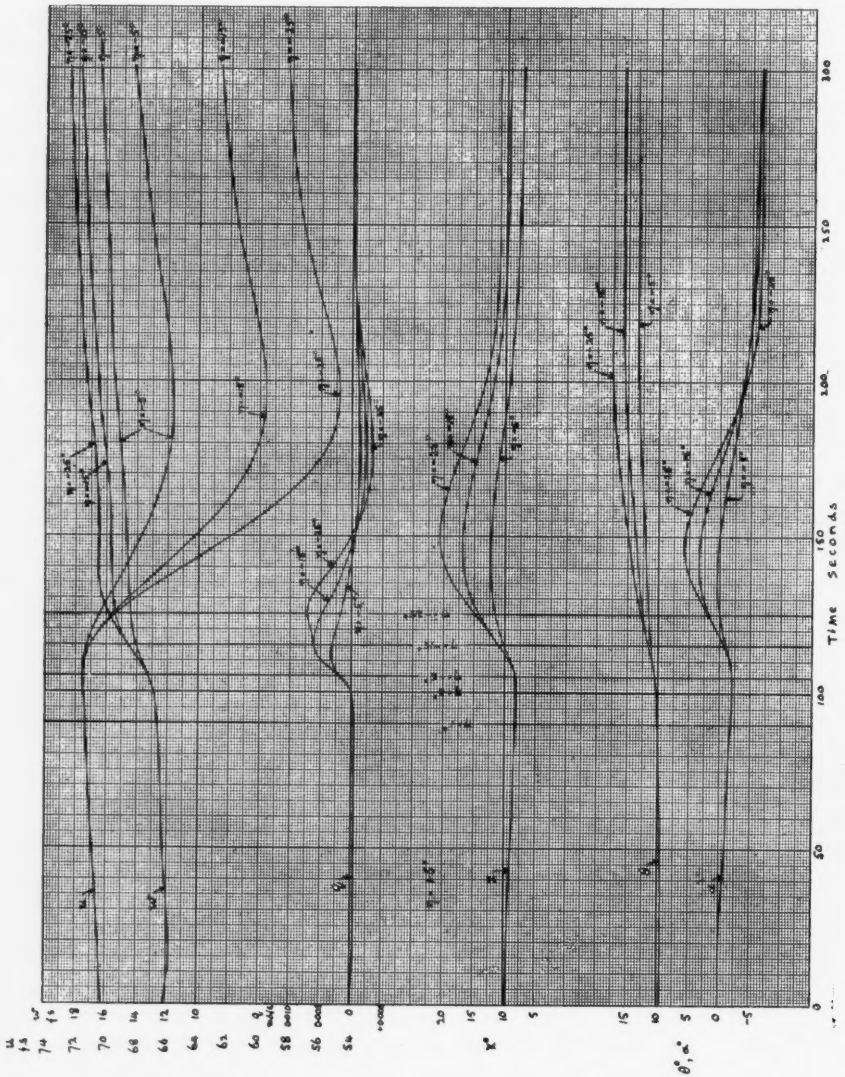


FIG. 5.

Cases A ($\eta = -5°$) *B* ($\eta = -15°$), *C* ($\eta = -25°$).
Values of u, w, q, χ, θ, α.

final downward path. With 15° elevators, the ship more than makes up the height lost during the first part of the case, but almost as soon as she has got back to her original height, she begins to fall. With 25° elevators, the ship climbs to 105 feet above her height at $t=0$ and then settles towards her equili-

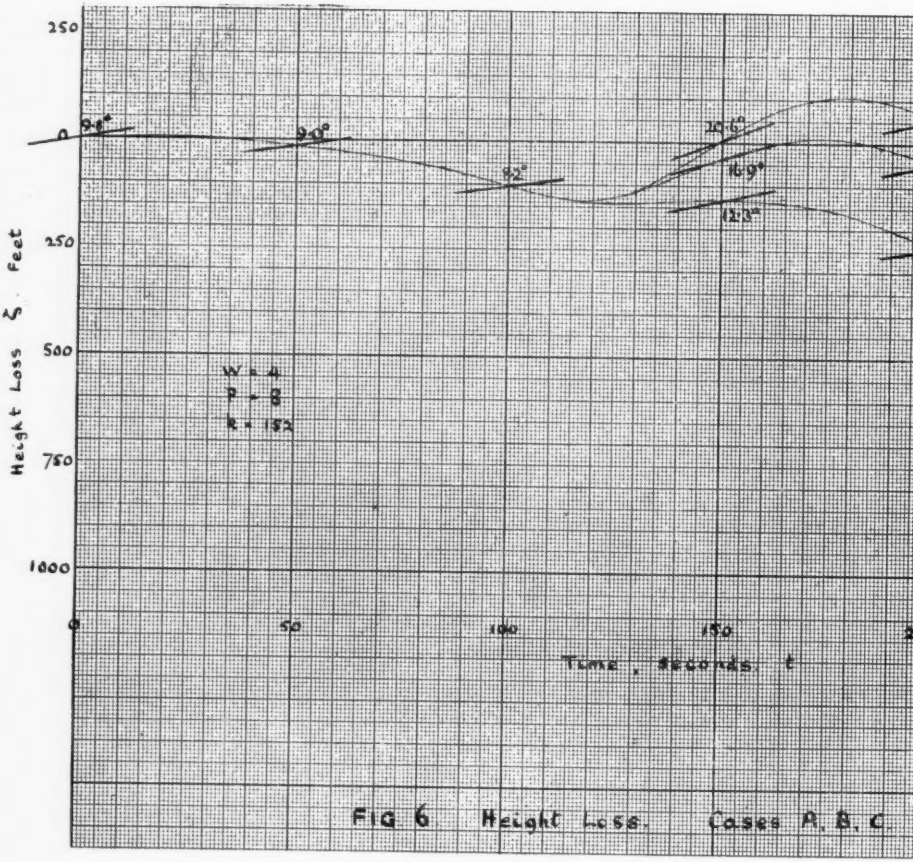
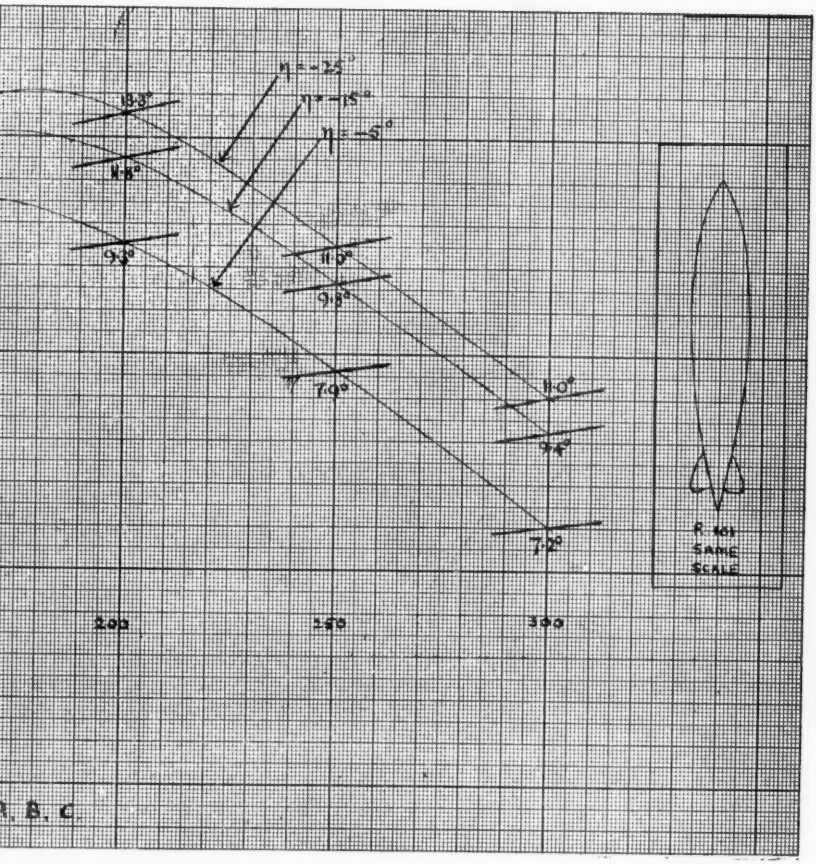


FIG 6 Height Loss. Cases A, B, C.


η = -25°
η = -15°
η = -5°
8.8°
4.8°
9.4°
11.0°
9.8°
7.9°
11.0°
9.4°
7.2°
R. 161
SAME
SCALE
200
250
300
A, B, C

brium path. At $t=300$, the ship is losing height at the rate of 3.5 feet per second approximately. Though the rate of loss of height is much the same in the three cases, the forward speed of the ship is very different, as the weight component, which has to be balanced by the engine thrust, increases with χ; the air speed of the ship is 70.3, 65.1 and 61.2 ft./sec. at $t=300$ for $\eta=-5^\circ$, -15° and -25° respectively.

Nose Heaviness: Airship Initially Horizontal

34. *Case D.*—Ship 12 tons heavy; 4 tons general heaviness ($W=4$), 8 tons loss of gas from gasbag 5 at $t=0$ ($P=8$, $k=152$). Leakage of 1 ton/min. from gasbag 5.

Initial conditions:—

$$V=71.3 \text{ ft./sec.}=42.2 \text{ knots}, \quad q=0,$$
$$\chi=\theta=a=0^\circ, \quad \eta=0^\circ.$$

At $t=0$, elevators are put up 1°/sec., and are kept at 5° up for the remainder of the time.

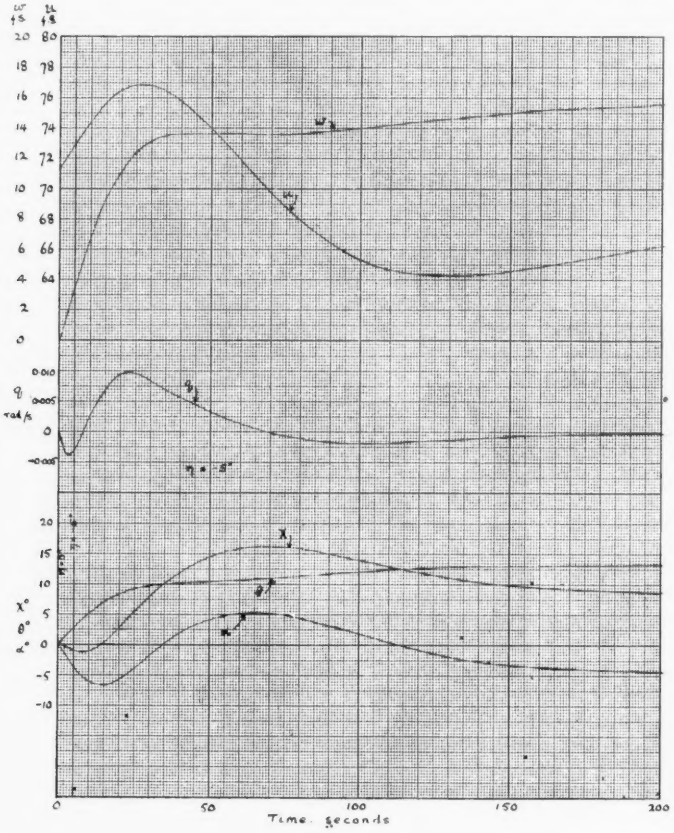


FIG. 7.

Case D. Values of u, w, q, χ, θ, a.

35. This case may be compared with the latter part of Case *A*, that is, the part after $t=100$ when the elevators are put up. The airship is not in equilibrium at the commencement of this case and there is no aerodynamic pitching moment to tend to counteract the effect of the nose heaviness. Consequently, the nose drops immediately. The gross heaviness, however, $(P+W=12)$ makes w appreciable and positive, giving a positive angle of pitch; and this in turn, helped by the elevators, brings into action an aerodynamic pitching moment which rapidly wipes out the effect of nose heaviness. The nose dips only to 1.1° down and the ship returns to the horizontal position after 14 secs. with the nose rising. The effect is well shown by the q curve. q becomes negative, reaching a value of -0.004 rad./sec., decreases to zero after 8 sec. and then rises to a maximum positive value of $+0.010$ at $t=22$. After that q decreases again, changes sign at $t=68$, attains a value of -0.002 at $t=105$, then slowly subsides towards zero.

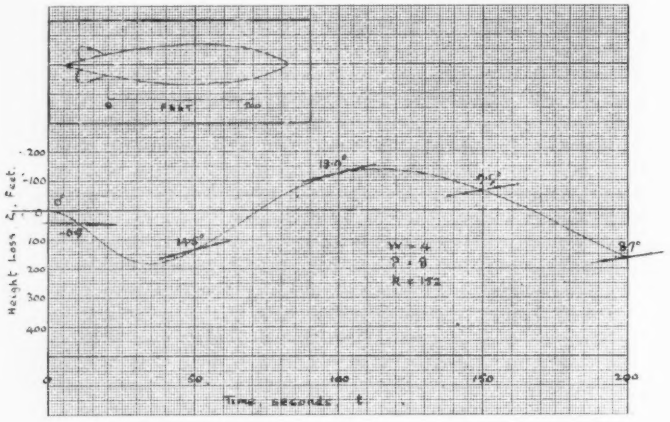


FIG. 8.
Case D. Height loss.

u increases at first, as the airship begins to fall, to 76.8 ft./sec., then as the nose rises and χ becomes large, u diminishes to 64.2 ft./sec. at $t=130$, after which it increases continuously towards the limiting value given in Table IV (§25) as the airship moves towards a steady path.

The ship loses height for the first 35 seconds, dropping 180 feet, but the inclination of the axis to the horizontal increases steadily after the first slight drop to a maximum value of 16.1° above the horizontal at $t=70$. χ and θ both increase and the ship climbs after $t=35$, regaining her lost height at $t=72$, and continuing to climb to 139ft. above her initial height, before beginning to sink slowly.

Nose Heaviness: Airship Initially 5° Nose Down

36. *Case E.*—Ship 12 tons heavy; 4 tons general heaviness $(W=4)$, 8 tons loss of gas from gasbag 5 at $t=0$ $(P=8, k=152)$. Leakage of 1 ton/min. from gasbag 5.

Initial conditions:—

$$V=71.3 \text{ ft./sec.}=42.2 \text{ knots}, \quad q=0,$$
$$\chi=\theta=-5^\circ, \quad \alpha=0^\circ, \quad \eta=0^\circ.$$

Elevators kept amidships throughout.

37. The heaviness is the same in this case as in the previous ones. The only difference is in the initial attitude and in the fact that the elevators are kept amidships throughout the case. Here it is presumed that the nose of the airship is initially 5° down with the ship moving on a horizontal path, so that there is an aerodynamic pitching moment acting in the same direction as the nose heaviness forcing the nose down. The elevators are kept amidships in order to observe the path of the ship with no effort made to correct any height loss.

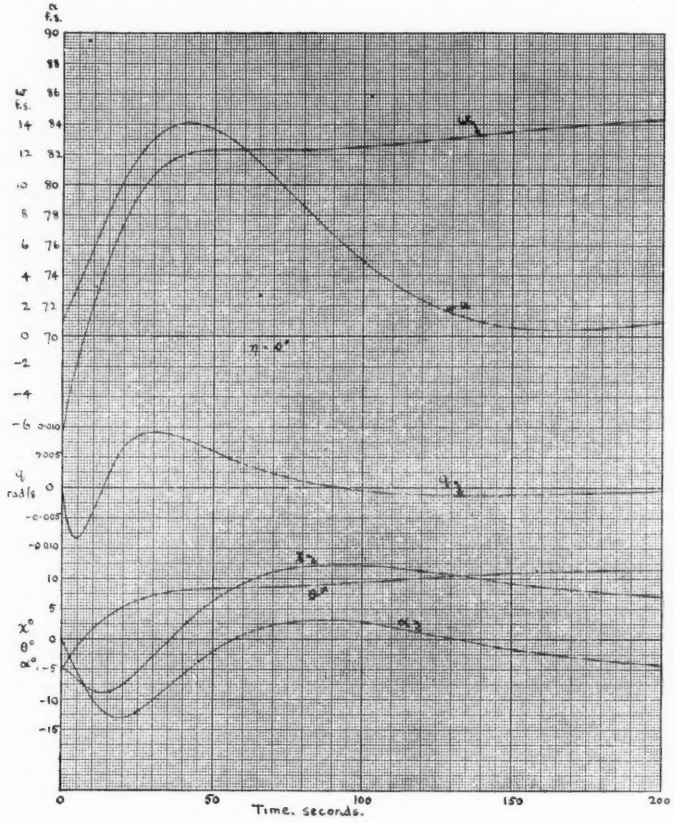


FIG. 9.

Case E. Values of u, w, q, χ, θ, α.

As would be expected, the first result is to drive the nose down considerably further than in Case *D*, but Fig. 10 shows that the ship recovers from the disturbance, performs an oscillation similar to that of the preceding case and settles down on an inclined path, with her nose 7° up at $t=200$.

The general considerations are the same as in Case *D*, the first dip now reaching 8.8° down (3.8° below the initial inclination) and the nose then begins to rise. The ship becomes horizontal at $t=35$ and χ attains a value of 12.3° up before beginning to fall towards its equilibrium value. The recovery is due to the gross heaviness of the ship, which decreases θ numerically and rapidly makes it positive. w quickly reaches a steady value of 12.3 ft./sec. then increases slowly as the

heaviness gets larger due to leakage of gas. The changes in θ follow those in w very closely. u increases more than it did in Case D, owing to the greater component of the weight during the dive. It rises to a value of 84.1 ft./sec., then falls to a minimum of 70.4 ft./sec. at $t=170$. At the end of the case, it is just beginning to rise again towards its final value.

Even with the wind above the nose initially and no elevator movements, the airship only loses 580 feet in height before she begins to climb. In this case, the ship does not return to her height at $t=0$; after regaining 200 feet of height she begins to drop again and settles down on a steady path with her nose above the horizontal.

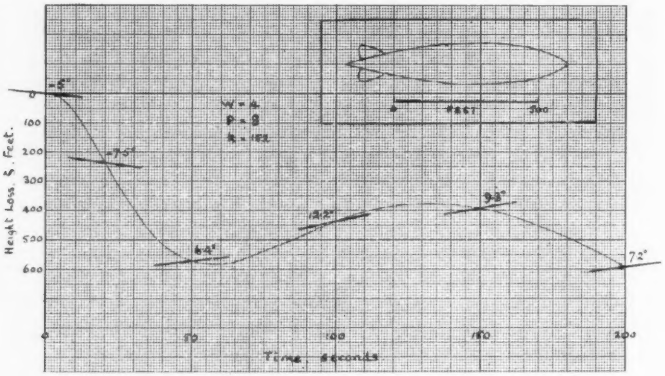


FIG. 10.

Case E. Height loss.

Deflation of Adjacent Gasbags: Increased Drag

38. *Cases F, G_1, G.*—No total heaviness; 8 tons loss of gas from a gasbag ($P=8$) at $t=0$. Ship's lightness apart from loss of gas ($W=-8$) is presumed to be obtained by dropping ballast. Leakage of 1 ton/min. of gas from the gasbag.

Drag of airship increased (-0.002 added to X_θ) due, for example, to envelope tear.

Initial conditions:—

$$V=60 \text{ ft./sec.}=35.6 \text{ knots}, \quad q=0,$$
$$\chi=\theta=\alpha=0^\circ, \quad \eta=0^\circ.$$

Case F.—Loss from gasbag 5 ($k=152$).
At $t=25$ secs., elevators are put up 1°/sec. to 25° up.

Case G_1.—Loss from gasbag 4 ($k=200$).
At $t=25$ secs., elevators are put up 1°/sec. to 25° up.

Case G.—Loss from gasbag 4 ($k=200$).
At $t=30$ secs., elevators are put up 1°/sec. to 25° up.

39. In these cases and in a number of the succeeding ones, an allowance has been made for an increase in drag as mentioned in §14. An addition of 0.002 has been made to the numerical value of X_θ for all attitudes of the ship and all elevator settings, neglecting any effects on Z_θ and M_θ. The increased drag would reduce the speed of the ship at 0° pitch, elevators amidships, from 55 to 38.8 knots with the assumed thrust, if the ship were flying on a horizontal path.

Cases F and G_1 give the comparative effect of equal loss of lift from two adjacent gasbags, numbers 5 and 4 respectively. Except for this the cases are

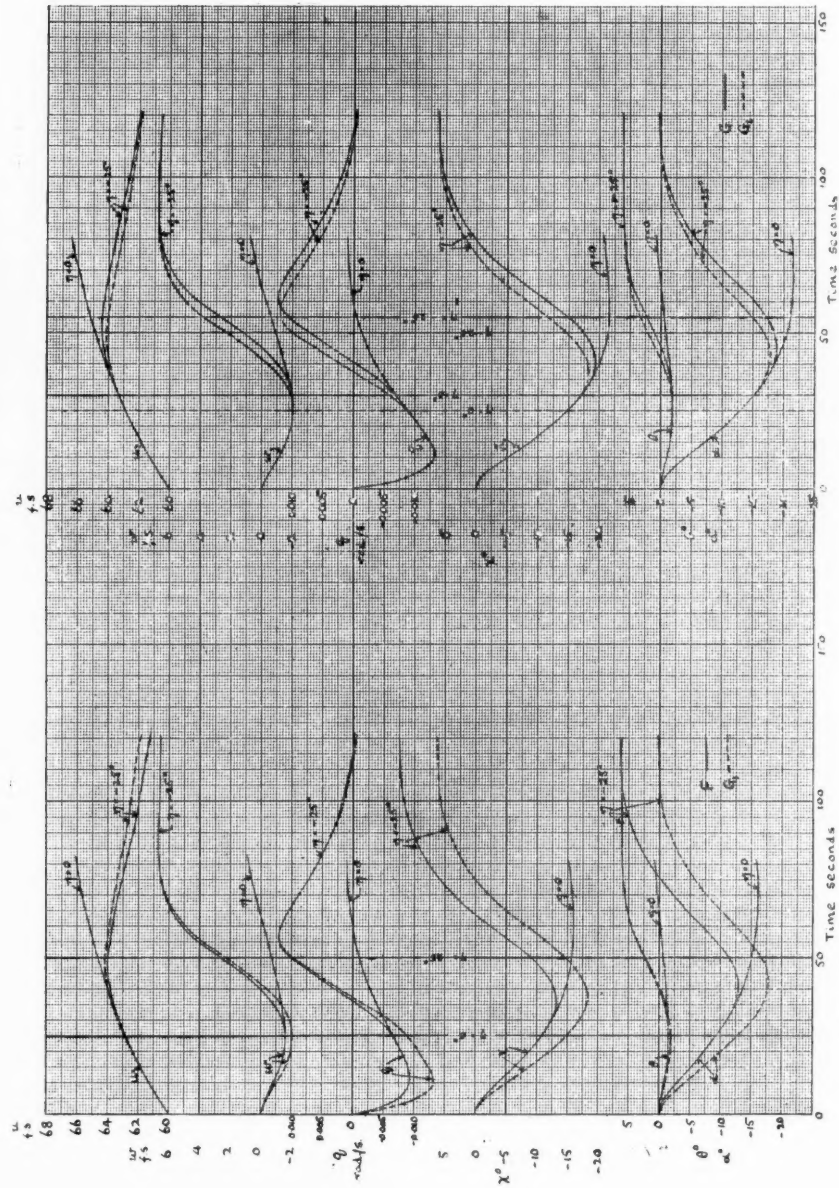


FIG. 11.
Cases F, G_1. Values of u, w, q, χ, θ, a.

FIG. 12.
Cases G_1, G. Values of u, w, q, χ, θ, a.

identical. The ship is not in equilibrium in either case and there is no aerodynamic pitching moment to offset the upsetting moment due to nose heaviness. The pitching moment is 33 per cent. larger in Case G_1 than in Case F, and this is immediately evident in the much greater variation in q in the first few seconds as the nose sinks below the horizontal. At the end of 25 seconds, the axis is 10.8° down in Case F and 14.8° down in Case G_1, with a negative angle of pitch of about 2° in both cases. The elevators have not been put up until the nose is pitched to this extent, but the curves of height loss indicate that the elevators would pull the ship out of the dive, if she had sufficient height.

The effect of the greater nose heaviness is most noticeable in the curves for w, q, χ and a. The values of w, q and θ all settle down to practically the same values in the two cases after the ship has recovered from her first oscillation.

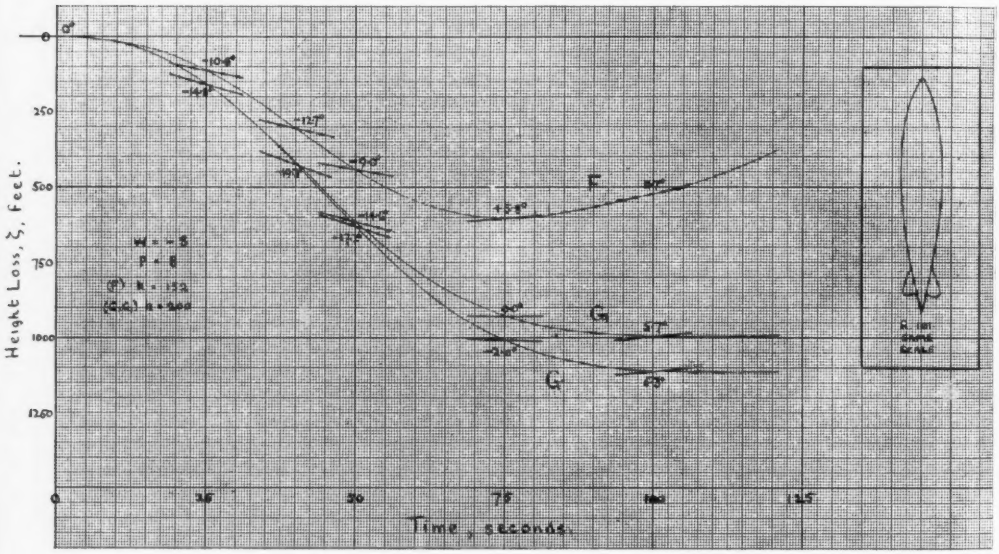


FIG. 13.
Cases F, G_1, G. Height loss.

The curves for χ and a, however, are markedly different. This is due to the fact that χ is the integral of q, so that the effect of any difference in q persists throughout the case.

The airship has no gross heaviness at $t=0$ and the nose heaviness makes the incidence negative at first; θ changes sign at $t=40$ in Case F and at $t=42$ in Case G_1. So long as θ is negative, there is an aerodynamic pitching moment helping to force the nose down and q attains a value of -0.009 in Case F and -0.013 in Case G_1 before it begins to decrease. q subsides steadily and would become zero in the two cases at $t=60$ if the elevators were kept amidships, as is shown by the curves for $\eta=0$ in Figs. 11 and 12. Putting the elevators up brings the ship out of the dive more rapidly and, with up elevators, q changes sign at $t=36$ and $t=38$ in Cases F and G_1. It becomes positive and rises to $+0.012$ in the two cases at $t=55$ after the elevators are fully up. After that, q slowly decreases and the values are practically identical.

With no elevator movements, the inclination of the axis to the horizontal reaches a maximum of 16° down at $t=60$ in Case F, and 21.5° down at $t=55$ in Case G_1 and the recovery would be very slow. The assumed elevator movements do not allow the ship to go below 13.1° down at $t=36$ in Case F and 18.2° down at $t=38$ in Case G_1, and the nose rises as rapidly as it fell, becoming horizontal again 64 seconds and 75 seconds after zero time in the two cases. The nose continues to rise to a maximum of about 12.5° up and 6.5° up respectively before the airship begins to settle down on her steady descent with her nose above the horizontal.

40. The curves for α follow the curves for χ as the values of θ are small throughout, owing to the slight heaviness of the ship; the gross heaviness is merely the leakage during the few seconds under consideration. If the ship were heavy, the recovery from the first dive would be much more rapid, though she might lose more height. This paradoxical result became obvious as the cases were calculated, as θ and w are more or less proportional to the gross heaviness and a large θ gives rise to a large aerodynamic moment tending to raise the nose of the ship. Towards the end of these cases, θ is steady at about 6° with little gross heaviness; whereas in Case C, where the elevators are also fully up but in which there is 12 tons gross heaviness, θ has a value of about 17°.

As regards loss of height in the two cases, the total lost in Case F is 600 feet at $t=75$; while in Case G_1 the loss is about 1,000 feet at $t=120$. The curves of height loss against time show that, in the latter case, the ship will probably settle down on her steady path with practically no recovery of height; her path is nearly horizontal with her nose 6° up at $t=120$. In Case F, the ship is climbing at the rate of 6 feet per second at $t=120$.

With the elevators amidships throughout, the curves for α indicate that the ship would be losing height rapidly, the angle of incidence being roughly zero, so that the ship would be inclined some 16° in Case F and 21.5° down in Case G_1. Her path relative to the air would be inclined down at the same angles.

Effect of Delay in putting Elevators up

41. The changes in the variables due to delay in giving the ship up elevator is shown by a comparison of Cases G_1 and G in Fig. 12. The conditions governing the cases are exactly the same except that in Case G the elevator movement has been delayed 5 seconds, the axis being inclined 17.1° down before the movement is begun in Case G as against 14.8° in Case G_1. The cases are identical to $t=25$.

The curves are very similar, running parallel to each other 5 seconds apart, all the effects being delayed that amount. There are differences in the curves for χ, α and height loss; the differences are all due to the fact that χ is the integral of q, whilst α, and therefore also the loss of height, is derived from χ. Also the value of u is larger in the delayed case (G_1) as the height loss is greater there. The maximum downward inclination of the axis is increased from 18.2° to 19.3° and the value of α from $-17.8°$ to $-18.8°$ by the delay.

The curves of height loss plotted in Fig. 13 show that at $t=120$, the ship would have lost 116 feet more in Case G than in Case G_1. At that time she would have recovered from the dive and would begin to settle down. The flight paths after 120 seconds would be parallel.

Ship Normal. Effect of Down Elevator

42. *Cases H, H_1.*—No heaviness. No loss of gas ($W=0$, $P=0$). Ship normal and in trim.

Initial conditions:—

$$V=91 \text{ ft./sec.}=53.3 \text{ knots}, \quad q=0,$$
$$\chi=\theta=\alpha=0°, \quad \eta=0°.$$

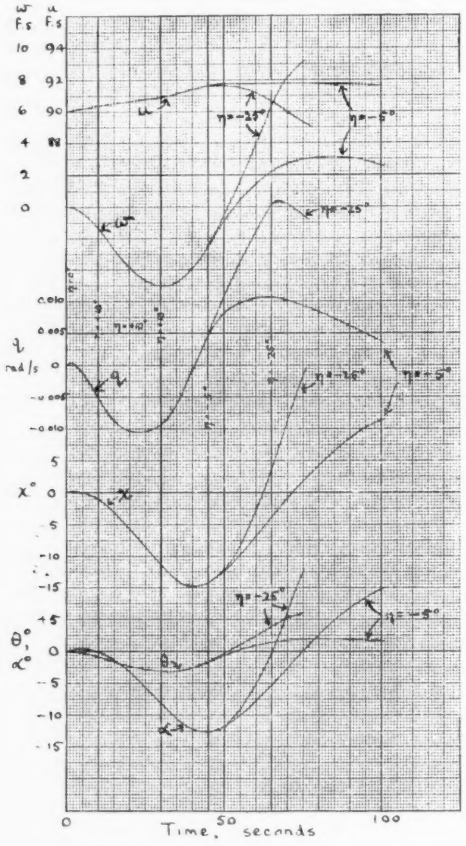
At $t=0$, elevators are put *down* at 1°/sec. to 10° down.

The elevators are kept at 10° down until $t=30$ secs., after which they are put up 1°/sec.

Case H_1.—Elevators are stopped at 5° up.

Case H.—Elevators are put up to 25° up.

43. In order to investigate the response of a normal ship to down elevator movements and to determine how long she would take to recover from the consequent dive, it has been assumed in this case that the elevators are put 10° down and



Case H $\eta \rightarrow -25°$
Case H_1 $\eta \rightarrow -5°$

FIG. 14.

Cases H, H_1. *Values of* u, w, q, χ, θ, α.

kept there until the nose is well below the horizontal. The ship has been taken to be neutral in weight, undamaged and in trim. The airship naturally responds to the elevator movements and begins to dive. Her nose is 0.9° down when the elevators are stopped 10° down and her downward inclination increases to 11.4° down at $t=30$. The elevators are then assumed to be put up as quickly as possible. The ship continues to dive, as the elevators are not amidships until $t=39$ and she reaches her worst nose-down position with $\chi=-14.8°$ at $t=41$.

She begins to recover though her angle of incidence remains negative until after $t=50$ as there is a large w component ($w=-5.1$) to be overcome. In this case, as in the previous ones (F and G_1, §40) recovery would be more rapid if the ship had some gross heaviness; θ does not become large at any time during this case.

With elevators stopped at 5° up, the ship loses 727 feet in height in 75 seconds, having just returned to a horizontal attitude at that time. She then climbs and regains 188 feet of height in the next 25 seconds, by which time her nose is 11° up. With full up elevator, her recovery is much more rapid; after losing 641 feet of height in 65 seconds she climbs quickly. At $t=80$ she has recovered 113 feet and is tilted 25° nose up.

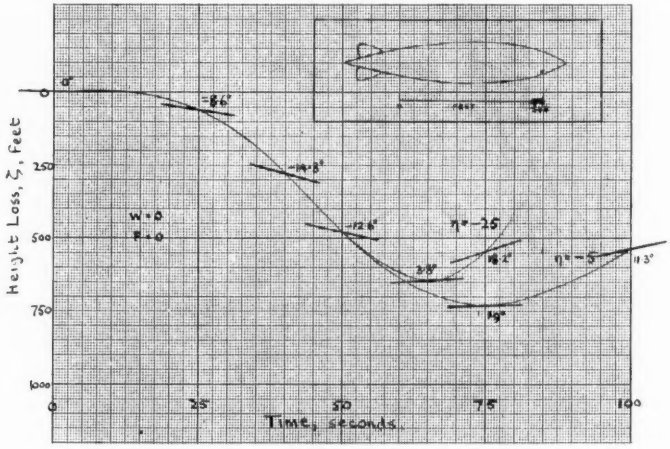


FIG. 15.
Cases H, H_1. Height loss.

As there is no change of potential energy, the ship being neutral, the values of u remain nearly constant, except that with 25° up elevator the consequent increase of drag causes a sharp decrease towards the end of the case. The transverse velocity, w and θ both become negative and remain so until after $t=50$, thenceforward increasing steadily.

After a very slight initial positive value (due to the fact that the ship is not in exact equilibrium at first) q goes to −0.010 rad. per sec., then decreases to zero at $t=41$, changes sign and increases rapidly so long as the elevator movements are continued. When the latter cease, q begins to decline.

Nose Heaviness, Ship Light: Shutting Down Engines

44. *Case J.*—Ship 2 tons light; 8 tons loss of gas from gasbag 4 ($P=8$, $k=200$) at $t=0$. Ship's lightness ($W=-10$) presumed to be due to dropping of ballast and to consumption of fuel. Leakage of 1 ton/min. of gas from gasbag 4.

Drag of airship increased (−0.002 added to X_θ).

Initial conditions:—

$$V=60 \text{ ft./sec.}=35.6 \text{ knots}, \quad q=0,$$
$$\chi=\alpha=\theta=0°, \quad \eta=0°.$$

At $t=30$ secs., elevators are put up 1°/sec. to 25° up.

Case K.—The same as Case *J* as far as $t=80$ secs.

At $t=80$, the engines are shut down, the airscrew thrust being assumed to vanish after that time.

45. In Cases F and G, the airship was assumed neutral and it was remarked in the discussion of those cases that it is more difficult to pull a light ship out of a dive than a heavy one with the same nose heaviness. In Cases J and K the argument has been carried further and the ship assumed to be 2 tons light. The conditions chosen here are the same as those for Case G except for the alteration

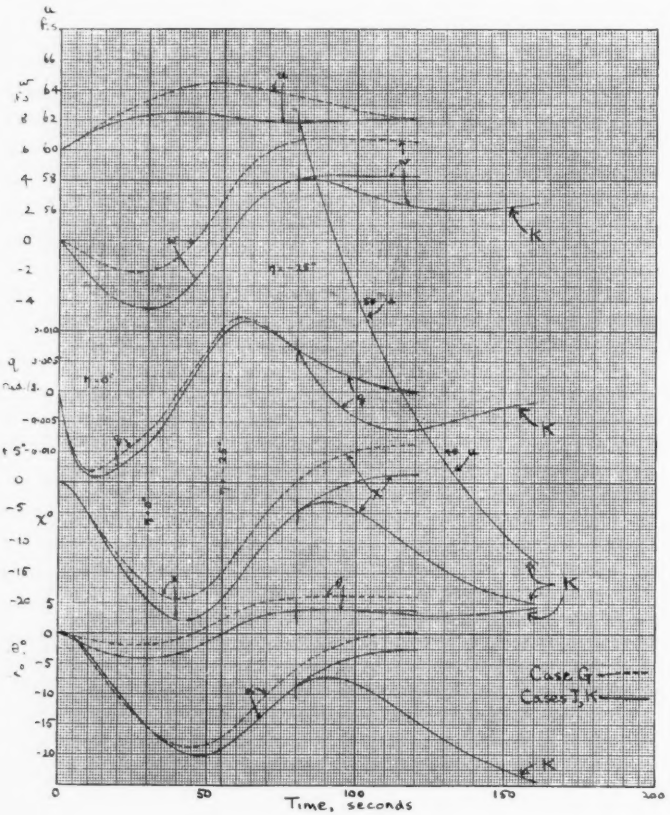


FIG. 16.

Cases G, J, K. Values of u, w, q, χ, θ, α.

in gross heaviness; so that the differences are due only to the lightness of the ship. The curves for Case G are shown dotted in the figures.

As the ship is not in equilibrium at the start, her nose begins to sink, and she dives. The lightness in Case J causes the ship to lose less height at first than the neutral ship of Case G. Later, the curves of height loss cross, and the neutral ship, with up elevators has lost only 1,110 feet in 100 secs. as compared with 1,225 feet for the lighter ship. The flight path is horizontal in Case G at that time, whereas the lighter ship is still losing height. The crossing of the curves may be explained by the fact that in time the lightness gives the ship an

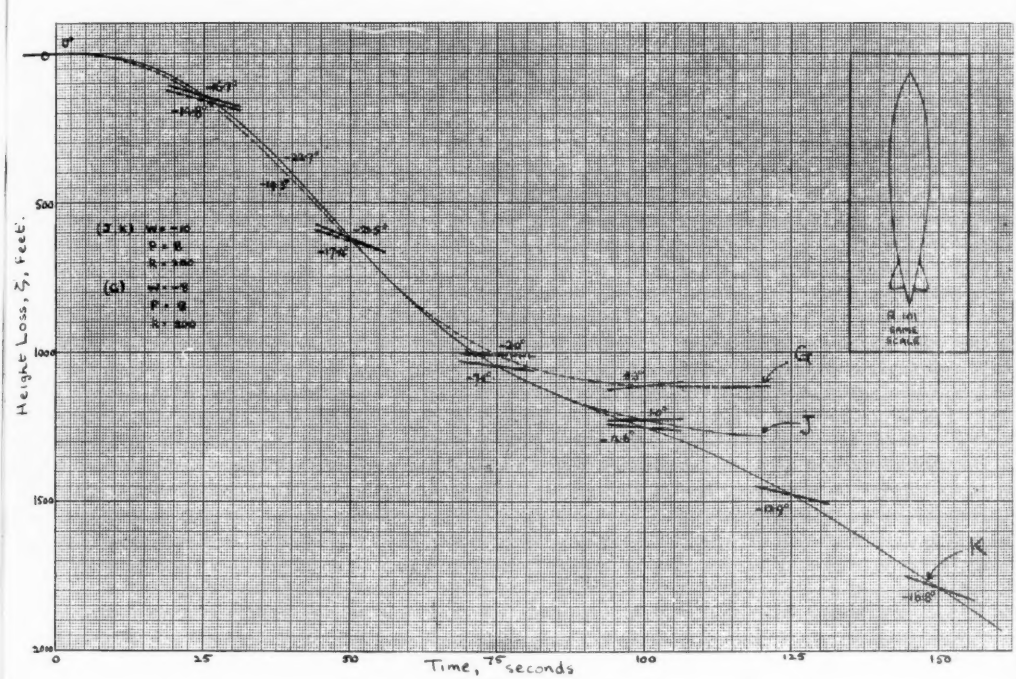


FIG. 17.

Cases G, J, K. Height loss.

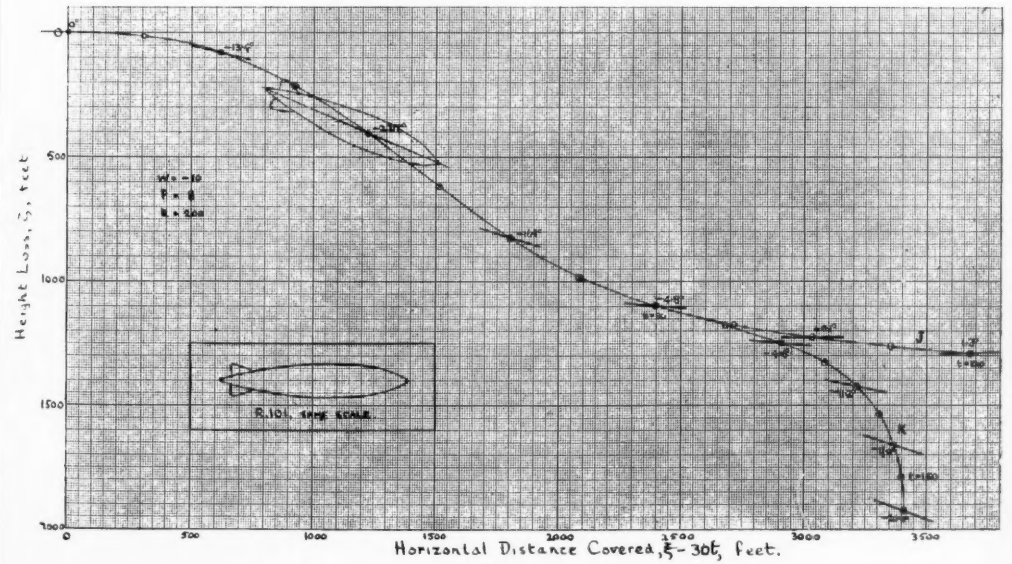


FIG. 18.

Cases J, K. Flight path. Natural wind speed, 30 ft./sec.

angle of incidence 2.5° less than that for the neutral case, and the aerodynamic lift and moment are very much smaller.

The value of u in Case J is less than in Case G as the ship is diving and the lightness tends to retard her. The increase at first is due to the thrust being larger than the drag at the initial speed of the ship.

In Case J, w reaches a value of -4.5 ft./sec. (as compared with -2.0 in Case G), then diminishes to zero and finally becomes practically constant at 4.3 ft./sec.; the corresponding value in Case G is 6.8 ft./sec. The values of θ in the two cases are then 4° and 6.5° respectively.

The lighter ship dives to a steeper angle ($-22.7°$ compared with $-19.3°$) and takes 20 seconds longer than the neutral ship to return to the horizontal, beyond which it only proceeds to 1° nose up. The curves for α show that the neutral ship is just able to maintain height after recovering from the dive, though she will not recover more than a few feet of the lost height. On the other hand, the α curve for the lighter ship will probably not reach the zero line, *i.e.*, she will continue to lose height. At $t=120$ she is still dropping at the rate of 3 ft./sec.

46. At $t=80$ in Case J, it has been assumed further that the engines are shut down to give zero airscrew thrust; the resulting motion is designated Case K. The effect is immediately obvious in the u curve, u dropping very rapidly owing to the deceleration of the ship. The continuous decrease in the aerodynamic moment allows the nose heaviness to pull the nose down. The leakage of gas makes the ship neutral at $t=120$, but in spite of her lightness up to that point she loses height at a greater rate as soon as the engines are shut down. She does not recover to more than 7.3° nose down, after which she dives more steeply, and at $t=160$ she has lost 1,920 feet in height and her nose is 20° down.

The curves of loss of height for Cases G, J and K have been plotted on a time base in Fig. 17. In Fig. 18 the flight path of the ship is given for Cases J and K, assuming that she is flying into a head wind of 30 ft./sec. This shows the difference in the paths due to shutting down the engines in a very marked manner. The time has been indicated by circles every 10 seconds, and Case K has been carried 40 seconds further than Case J.

Gust: Ship 4 tons heavy: Dropping of Ballast

47. *Case L.*—Ship 4 tons heavy; 8 tons loss of gas from gasbag 4 ($P=8$, $k=200$); ship's lightness apart from loss of gas ($W=-4$) presumed to be due to consumption of fuel. Leakage of 1 ton/min. of gas from gasbag 4.

Drag of airship increased (-0.002 added to X_θ).

Initial conditions:—

$$V=70 \text{ ft./sec.}=41.5 \text{ knots}, \quad q=0,$$
$$\chi=5°, \quad \theta=1°, \quad \alpha=4°, \quad \eta=+7° \text{ (down)}.$$

At $t=10$, elevators are put up to 1° per 2 sec. to $\eta=+1°$.

At $t=24$, elevators are put up 1°/sec. to 25° up.

At $t=50$, engines are shut down (airscrew thrust zero) and 6 tons ballast are dropped.

From $t=16$ to $t=25$, airship encounters a gust, roughly equivalent to an increased horizontal wind speed of 20 ft./sec. and 4.5 ft./sec. down.

Case L_1.—The curves marked L_1 are a continuation of Case L beyond $t=50$ with no ballast dropped and with full engine thrust.

The curves marked α in Fig. 19 apply to motion under the same conditions as Case L, but without the gust.

The flight path is given in Fig. 20, assuming the ship to be flying against a head wind of 30 ft./sec.

48. The considerations which led to the choice of the initial conditions in this case and in some of the following ones have already been set out in § 28.

The effect of a gust striking the airship above the nose has been examined here. A simplification was made in the equations dealing with the gust, namely:—

$$u' = u + 20,$$
$$w' = w - 4.5 + 20 \sin \chi,$$

instead of using the equations given in §6. These equations represent a gust of which the horizontal component increased from 20.65 to 21.90 ft./sec. and the vertical component decreased from 4.44 to 4.25 ft./sec. during the period of the gust. In this case as in all the following cases which include a gust, the value

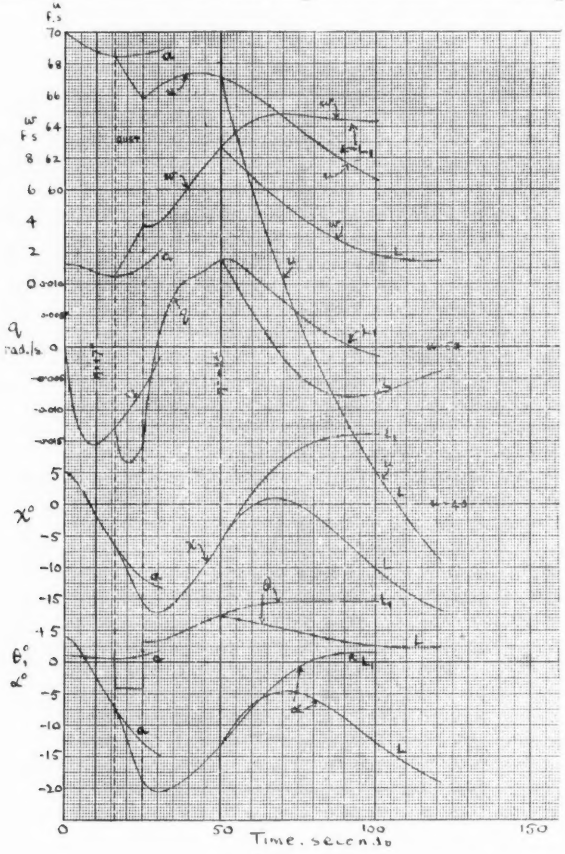


FIG. 19.

Cases L, L_1. Values of u, w, q, χ, θ, α.

of θ' has been plotted instead of θ for the duration of the gust, as the aerodynamic quantities have to be obtained at the incidence θ'.

The ship climbs a little at first, but her nose drops steadily owing to the nose heaviness, and it has therefore been assumed that the elevators were eased off. The ship is, however, 6.7° nose down when the gust strikes her, and the nose is forced to 15.5° below the horizontal at the end of the gust. The nose continues to drop to 17.2° down before rising. With the same other conditions, but with-

out the gust the corresponding nose down angles are 11.7° and 13.1°. The elevator movements are continued until at $t=50$ the extreme up position is reached. The nose rises continuously if the conditions are then maintained (Case L_1) and at $t=58$ the airship is horizontal; a maximum of 11.2° nose up is reached before the ship begins to settle down. At $t=100$ she is beginning to climb slowly, having lost a total height of 860 feet.

In Case L, it was assumed that at $t=50$ the engines were shut down and 6 tons of ballast dropped, without affecting the static moment of the ship. The effect of the smaller heaviness is seen at once in the diminution of the numerical value of a and in the fact that the flight path is slightly above that for Case L_1 for some 15 seconds after $t=50$. The nose of the ship does not, however, rise

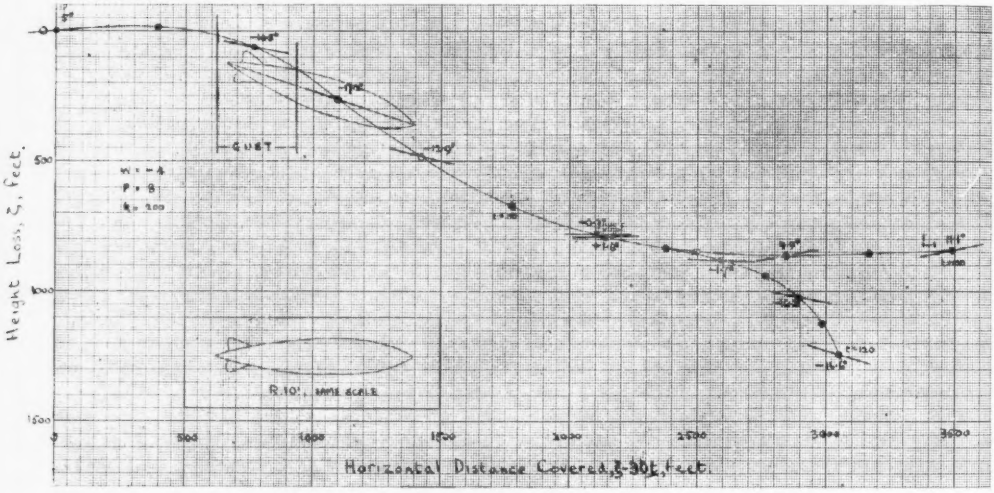


FIG. 20.

Cases L, L_1. Flight path. Natural wind speed, 30 ft. sec.

to more than 1° above the horizontal, after which height is lost more rapidly, and the nose drops again; an angle of 16.6° down is reached at $t=120$, by which time she has dropped 1,240 feet. The general effect of dropping ballast is that it tends to reduce w and therefore θ; and the corresponding aerodynamic lift and moment fall off. Added to this is the fact that with the loss of the thrust the speed falls, and this also causes a continuous reduction in the aerodynamic quantities. The airship thus dives steeply, whereas if the conditions of thrust and heaviness were maintained her nose would rise and she would ultimately settle down, falling steadily with her nose above the horizontal, as in the previous cases.

Gust: Ship 8 tons heavy: Dropping of Ballast

49. *Case M.*—Ship 8 tons heavy; 8 tons loss of gas from gasbag 4 ($P=8$, $W=0$, $k=200$) at $t=0$. Leakage of 2 tons/min. of gas from gasbag 4.

Drag of airship increased (-0.002 added to X_θ).

Initial conditions:—

$$V=84.4 \text{ ft./sec.}=50 \text{ knots}, \quad q=0,$$
$$\chi=5^\circ, \quad \theta=1^\circ, \quad \alpha=4^\circ, \quad \eta=+7^\circ.$$

At $t=10$, elevators are put up 1° per 2 secs. to $\eta=0^\circ$.
At $t=22$, elevators are put up 1°/sec. to 25° up.
At $t=36$, engines are shut down (airscrew thrust zero) and 6 tons ballast dropped.

From $t=10$ to $t=22$, the airship encounters a gust equivalent to an increased horizontal wind speed of 20 ft./sec. and 10 ft./sec. down.

The curves marked a (Fig. 21) give the values of the variables with the conditions of thrust and heaviness maintained beyond $t=36$.

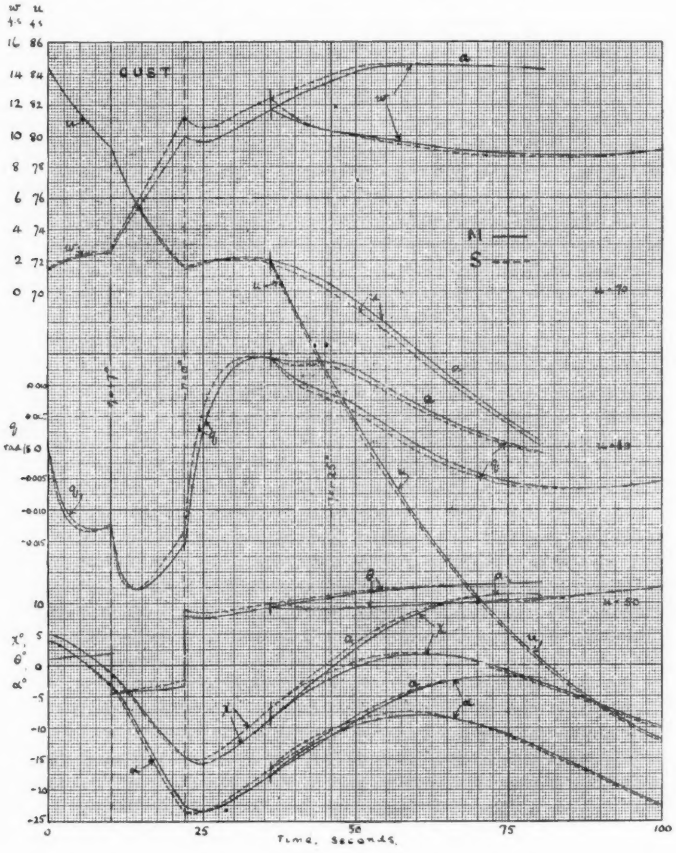


FIG. 21.

Cases M, S. Values of u, w, q, χ, θ, α.

50. The general conditions governing Case *M* are similar to those of the last case, but the initial speed of the ship has been increased to 84 ft./sec., and she is neutral in weight, apart from loss of gas. The gust has also been lengthened from 9 to 12 secs. and approximately doubled in intensity; and it strikes the ship earlier, when her nose is only 1° down. At this point there is a downward angular velocity of $q=-0.0125$ (0.7° per sec.); the gust increases this to a maximum value of -0.0225 (1.3° per sec.). Immediately after the end of the gust, q changes sign, and with assistance from the rising elevators, reaches

a value of +0.0145, afterwards subsiding slowly if no ballast is dropped and the engines are kept fully on. (Curves a of Fig. 21.) The nose of the airship is 14.7° down at the end of the gust and only dips 1° further before beginning to rise; she does not return to a horizontal attitude until about $t=50$, the elevators being fully up by that time.

Compared with Case L, where the maximum down angle is slightly greater, the recovery is more rapid in Case M; it occupies only 23 secs. as compared with 29 for Case L. This is partly accounted for by the higher speed of the ship; but is mainly due to the much greater value of θ at the end of the gust. The speed is reduced by the gust from 79.4 to 72.0 ft./sec. and the incidence increased from 1.8° to 8.0°.

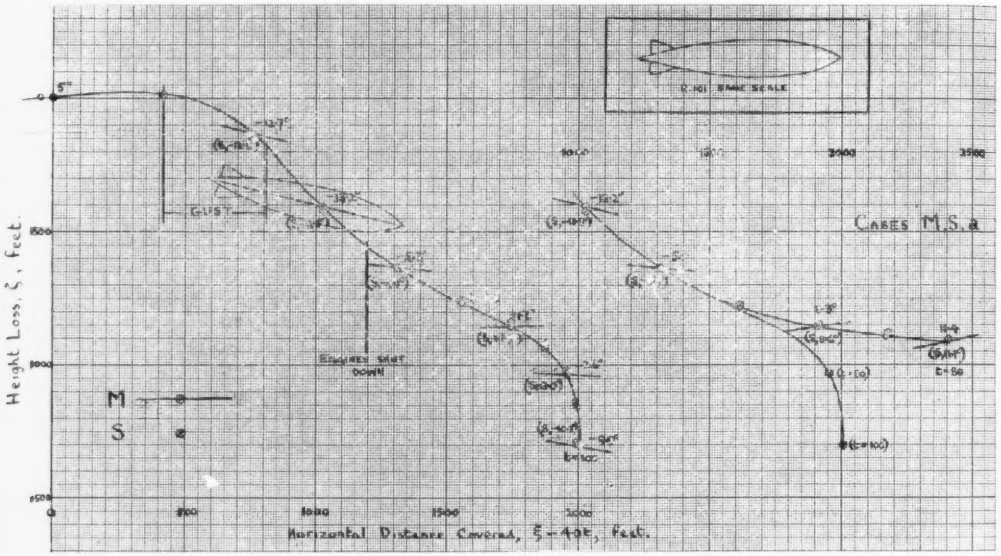


FIG. 22.

Cases M, S. Flight path. Natural wind speed, 40 ft./sec.

The flight path has been plotted (Fig. 22) for the airship flying against a head wind of 40 ft./sec. It is very similar to that of Case L, the first dive being accentuated by the gust, and being followed by a second dive after the engines are shut down and ballast is dropped. In this case the nose is 10° down and still falling when, at $t=100$, the ship has dropped 1,300ft. and is losing height at the rate of 16 ft./sec.

The greater gross heaviness in Case M (compared with Case L) prevents the ship from climbing at all after the first dive even if the conditions of thrust and heaviness are maintained. This is shown by the fact that the a curve does not return to zero; beyond $t=75$, a becomes more negative, so that the ship is beginning to fall more rapidly.

Shutting Down the Engines at Various Points

51. *Case* M_1.—Case M_1 embodies the original work carried out for the conditions given for Case M. The simplification in the gust equations similar to that

referred to in §48 was used, θ' being taken to be $\tan^{-1}(w-10\cos\chi+20\sin\chi)/(u+20)$. Thus it is difficult to define the gust exactly. There is an appreciable difference in the u term; but the other variables are little affected.

The results are of interest for comparing the effects of shutting down the engines and dropping 6 tons of ballast at three different times; at (*a*) $t=37$, (*b*) $t=42$, (*c*) $t=50$. The three sets of curves are marked *a*, *b*, *c*, respectively. It is instructive to observe how the variables tend to approach the same ultimate values irrespective of the time of shutting down the engines; the sets of curves are parallel towards the end of the case.

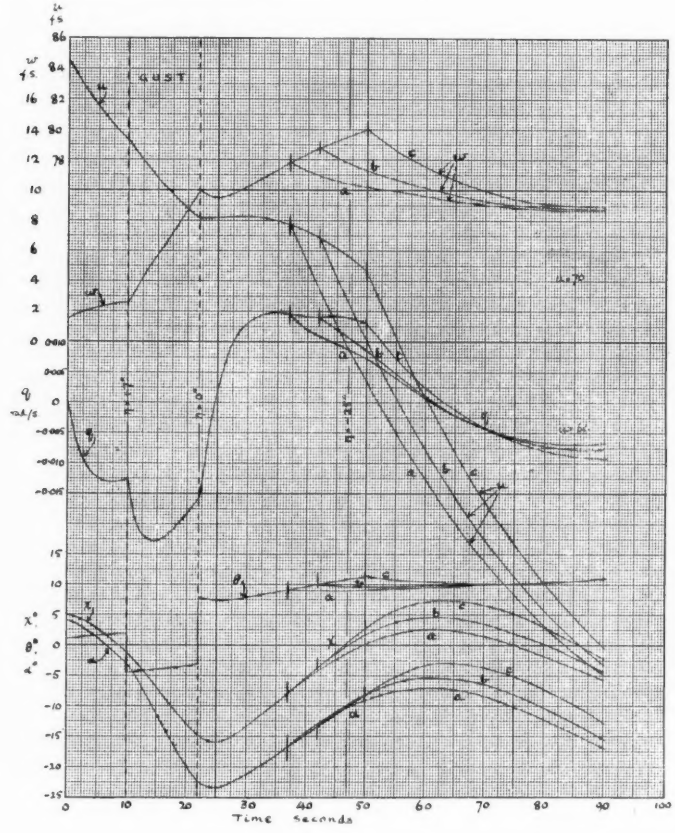


FIG. 23.

Case M_1. *Values of* u, w, q, χ, θ, α.

Gust: *Ship 6 tons heavy*: *Trapped Gas*

52. *Case N.*—Ship 6 tons heavy; 6 tons loss of gas from gasbag 3 ($P=6$, $k=250$) at $t=0$; 2 tons general heaviness and 2 tons (lift) of gas trapped in the hull ($W=0$). When the ship is 5° nose down, the trapped gas is assumed to go to the tail, giving a moment of 100 tons/ft., increasing to 400 tons/ft. when the ship is 10° nose down. Leakage of 2 tons/min. of gas from gasbag 3.

Drag of airship increased (-0.002 added to X_θ).

Initial conditions: –

$$V = 75.8 \text{ ft./sec.} = 45 \text{ knots}, \quad q = 0,$$
$$\chi = 5^\circ, \quad \theta = 1^\circ \quad \alpha = 4^\circ, \quad \eta = +7^\circ.$$

At $t = 10$, elevators are put up 1° per 2 sec. to $\eta = 0^\circ$.

At $t = 23$, elevators are put up 1°/sec. to 25° up.

At $t = 50$, engines are shut down (airscrew thrust zero) and 6 tons ballast dropped.

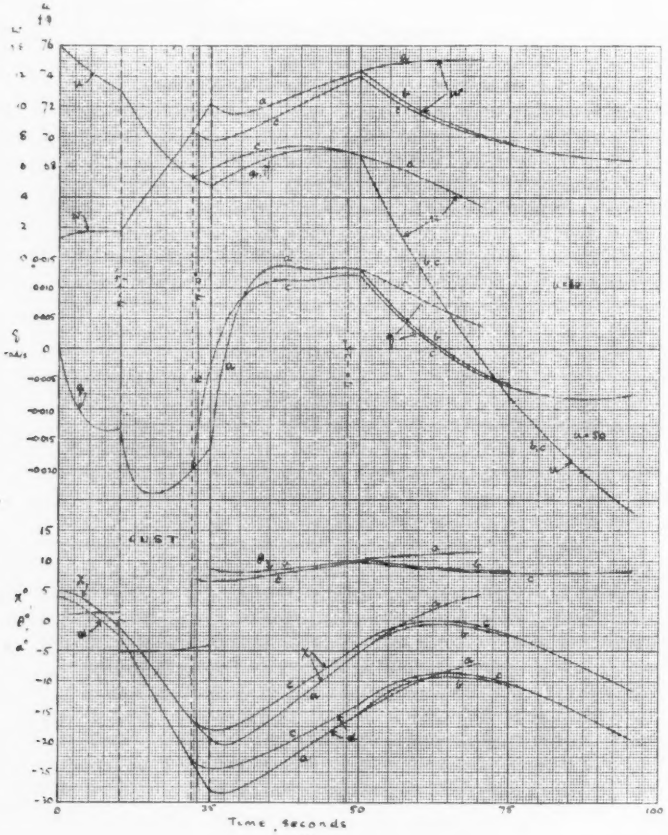


FIG. 24.

Case N. Values of u, w, q, χ, θ, α.

From $t = 10$ to $t = 22$, the airship encounters a gust, equivalent to an increased horizontal wind speed of 20 ft./sec. and 10 ft./sec. down. The effect of the extension of the gust to $t = 25$ is given in Fig. 24, curves *a*, *b*.

53. The alterations in the conditions of the preceding case are all such as would cause the airship to dive more steeply. The assumption of 6 tons loss of gas from gasbag 3 gives nearly the same pitching moment as 8 tons loss from gasbag 4, while giving less gross heaviness. The inclusion of the effect of trapped gas which moves to the tail as the nose sinks, helps to make the ship dive, and also counterbalances the 2 tons general heaviness assumed. It was

further assumed that the trapped gas did not affect the pitching moment until the ship was 5° nose down, when its moment was taken to be 100 tons/ft., increasing as the nose fell, to a maximum of 400 tons/ft., at which value it was assumed to remain constant. Suitable quantities were added to the right hand side of the moment equation to allow for this effect.

In the first place, the ship was subjected to a gust of 15 seconds' duration and the resulting motion is shown in curves *a* of Fig. 24, without shutting down engines or dropping ballast. The effect of carrying out these operations at $t=50$ is shown in curves *b* of the same figure. Curves *c* give the motion of the ship with the gust lasting only 12 secs., and the flight path in Fig. 25 is obtained with the shorter gust. The conditions assumed correspond to a gust of 60 ft./sec. blowing 9° down, if the speed of the natural wind is 40 ft./sec.; this natural wind speed is assumed in obtaining the flight path.

Curves *b* and *c* tend to the same values, showing that the effects of the different durations of the gust disappear in a short time.

The ship is 1.1° down by the nose when she is struck by the gust, and the longer gust forces her nose down to $-19.4°$; she sinks further to $-20.4°$, then the nose rises and becomes horizontal at $t=56$, the thrust being maintained. With engines shut down and ballast dropped at $t=50$, the ship just fails to reach a horizontal attitude, being 0.5° nose down at $t=65$, after which the nose sinks. The ship has lost height continuously and is 1,270 feet below her initial height at $t=80$; if the thrust and ballast are retained the height loss is about 50ft. less.

The shorter gust causes the ship to dive to $-16.2°$ at $t=22$; the nose continues to sink to $-18.1°$ before beginning to rise. By the time the elevators are fully up the ship has lost height to the extent of 815ft. (with the longer gust, the corresponding figure is 890ft.) and with engines shut down and ballast dropped she brings her nose just horizontal and then goes into a second dive, being 1,160ft. below her starting height at $t=80$, and 1,440ft. below at $t=100$, when she is 13.5° nose down.

Gust on Undamaged Ship: 6 tons heaviness

54. *Case P.*—Ship 6 tons heavy, undamaged and in trim ($W=0$, $P=0$). No leakage of gas.

Initial conditions:—

$$V=92.8 \text{ ft./sec.}=55 \text{ knots}, \quad q=0,$$
$$\chi=5°, \quad \theta=1° \quad \alpha=4°, \quad \eta=+7°.$$

At $t=10$, elevators are put up 1° per 2 sec. to $\eta=0°$.

At $t=23$, elevators are put up 1°/sec. to 25° up.

From $t=10$ to $t=22$, airship encounters a gust, equivalent to an increased horizontal wind speed of 20 ft./sec. and 10 ft./sec. down.

55. This case has been worked out to determine the motion of the ship, undamaged, in trim and 6 tons heavy, with meteorological conditions and elevator movements identical with those of Case *N*. The initial speed is higher, 55 knots, as that is the speed at which the airscrew thrust balances the longitudinal force for the undamaged ship. The shorter gust in Case *N* (12 sec. duration) has been chosen, so that the curves are to be compared with curves *c* of Fig. 24. The flight path is comparable with that in Fig. 25. In the flight path diagram, the gust appears longer, owing to the higher speed of the ship in Case *P*.

The nose of the undamaged ship is 3.6° up when the gust strikes it and is forced to 4.2° down by the gust, the elevators then being amidships. The nose does not sink below $-4.5°$ and up elevators bring the ship out very rapidly. In actual flight, the elevators would certainly not be put to their extreme up position, but in this case the elevator movements of Case *N* have been repeated. By the time the elevators are fully up, the undamaged ship has her nose 21° up and is climbing at the rate of 20 ft./sec. The ship only falls 140 feet below her initial

height and, with the meteorological conditions specified, she does not experience any difficulty in righting herself. The fall in the value of u towards the end of the case is due to the ship climbing and to the increased drag with up elevators.

Tail Heaviness

56. *Case Q.*—Ship 12 tons heavy; 4 tons general heaviness ($W=4$) and 8 tons loss of gas from an after gasbag ($P=8$, $k=-150$) at $t=0$. Leakage of 1 ton/min. of gas from the same gasbag.

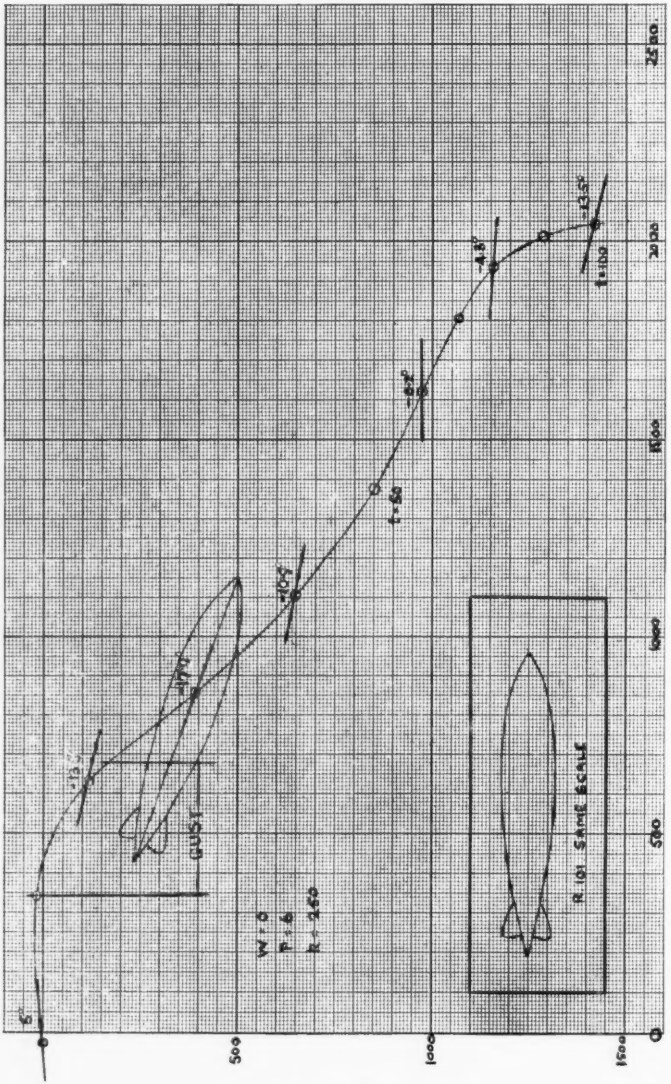


FIG. 25.

Case N. Flight path. Natural wind speed, 40 ft./sec.

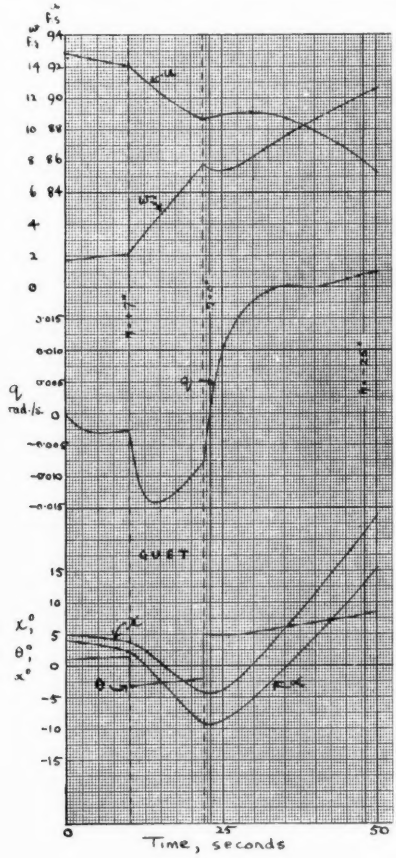


FIG. 26.

Case P. Values of u, w, q, χ, θ, α.

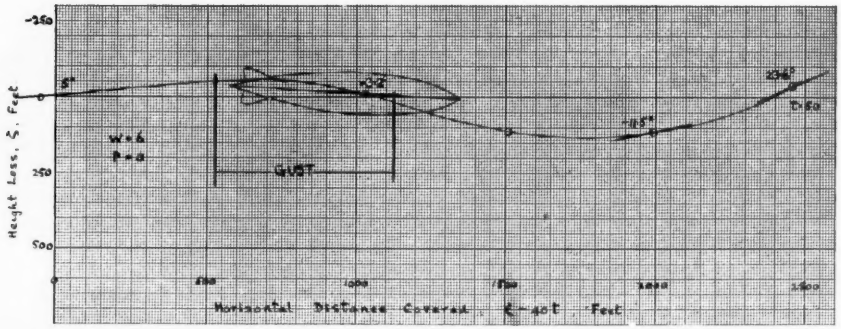


FIG. 27.

Case P. Flight path. Natural wind speed, 40 ft./sec.

Initial conditions:—

$$V=84.4 \text{ ft./sec.}=50 \text{ knots}, \quad q=0,$$
$$\chi=5^\circ, \quad \theta=5^\circ, \quad \alpha=0^\circ, \quad \eta=+25^\circ.$$

Elevators 25° down throughout.

57. As nose heaviness causes an airship finally to settle down with the nose above the horizontal, it is to be expected that tail heaviness will bring the ship down with her nose inclined upward at a much greater angle. In this case, the loss of 8 tons of gas aft ($k=-150$) has been considered, with a general heaviness of 4 tons, making the conditions analogous to the first cases as regards

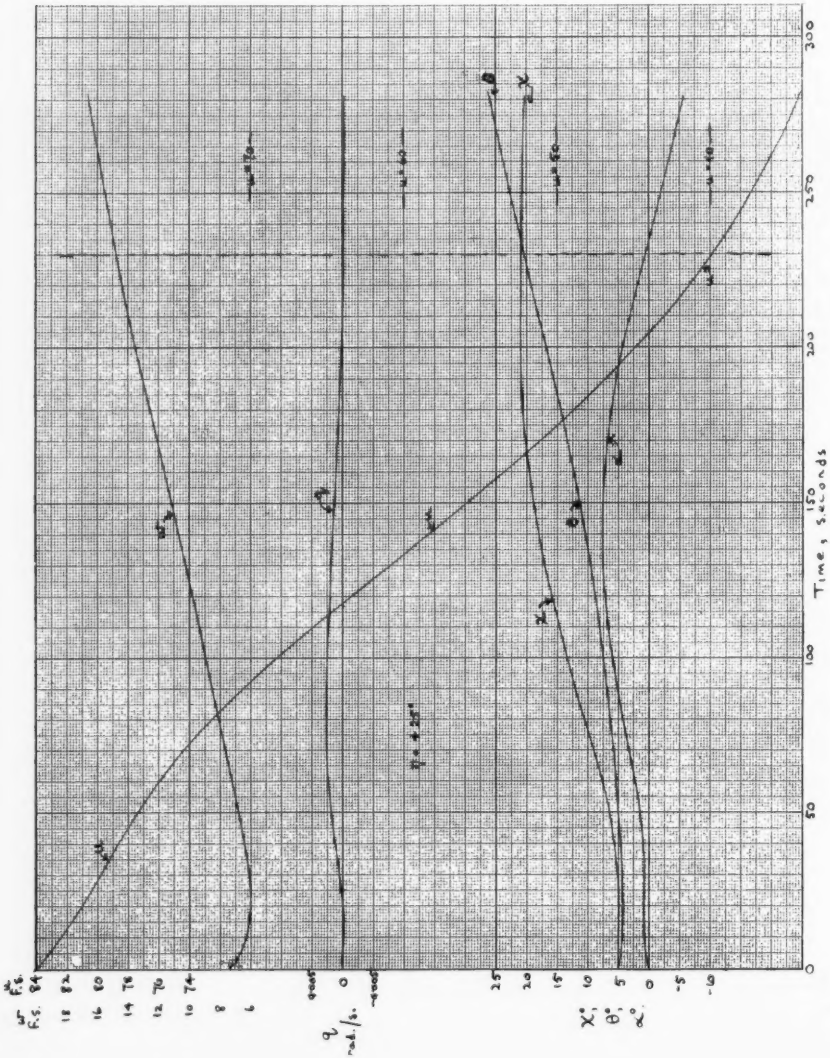


FIG. 28.

Case Q. Values of u, w, q, χ, θ, α.

weight, but with the particular heaviness opposite in effect. The elevators have been assumed to be 25° down all through in order to give the maximum negative pitching moment available. At the start the ship is approximately balanced as regards moment and transverse force, and is flying on a nearly horizontal path; but the increasing tail heaviness and the falling aerodynamic moment (the air speed drops continuously throughout the case) cause the nose to rise after about 40 secs.; and beyond this point the inclination increases continuously. The rotation also causes an increase in the incidence, so that the negative aerodynamic moment is thereby further decreased until the turning point in the M_θ curve has been passed. Since, however, χ is greater than θ until $t=235$, the ship climbs until that time, when she is 1,040 feet above her initial height.

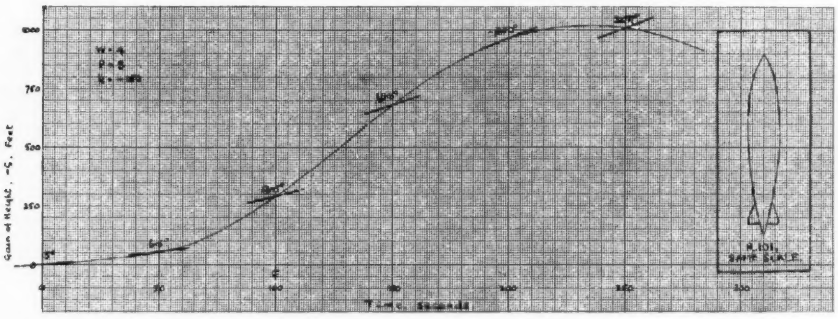


FIG. 29.

Case Q. Gain of height.

The most noticeable feature of the curves in Fig. 28 is the continuous fall in u and consequently in the air speed of the ship; u decreases from 84.0 to 34.2 ft./sec. and V from 84.4 to 37.8 ft./sec. for the time considered. The fall in speed is attributable to the fact that the ship is climbing rapidly, and to the increased drag resulting from the large angle of incidence.

The angular velocity q does not exceed 0.0026 (0.37° per sec.), but is positive until after $t=200$, the cumulative effect being 16° for χ, in addition to the initial 5°.

After $t=230$, the incidence was greater than 20° and it was necessary to extrapolate the curves for the aerodynamic forces and moment. The measurements on the model were only made up to $\theta=+20°$, but were taken to $\theta=-40°$. As the curves were nearly symmetrical the extrapolation could be made with a fair degree of certainty. All the calculations after $t=230$ were performed with the extrapolated values.

The airship after $t=235$ will begin to descend and will drop with increasing rapidity as θ increases while χ remains steady.

An attempt was made to obtain the final equilibrium values for this case, assuming complete deflation of the gasbag at $P=13$; but owing to the necessity for extrapolation of the curves the results are very approximate. The values obtained indicate that the variables would be of the following order:—

$$\theta=40°,\ \chi=20°,\ \alpha=-20°,\ V=16 \text{ knots.}$$

Nose Heaviness: Half Thrust

58. *Case R.*—Ship neutral; 8 tons loss from gasbag 5 ($P=8$, $k=152$); ship's lightness apart from loss of gas ($W=-8$) presumed to be due to dropping of ballast. Leakage of 1 ton/min. of gas from gasbag 5.

Initial conditions:—

$$V = 50 \text{ ft./sec.} = 29.6 \text{ knots}, \quad q = 0,$$
$$\chi = \theta = \alpha = 0^\circ, \quad \eta = 0^\circ.$$

The airscrews have been assumed to be giving half thrust only.

59. The value of the thrust taken in this case has been half the values given in Table III. The airship is not in equilibrium at the start, and the nose heavi-

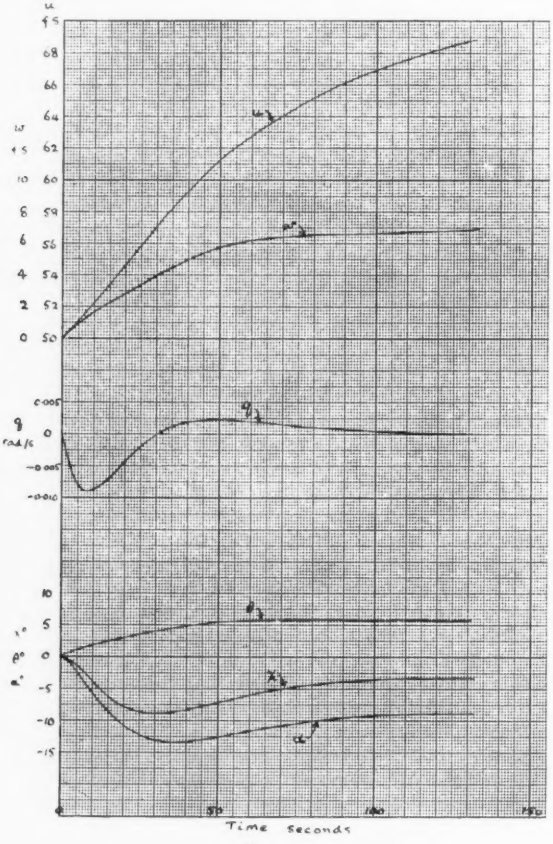


FIG. 30.

Case R. Values of u, w, q, χ, θ, α.

ness forces the nose 9° down in the first 25 seconds. The angle of incidence increases continuously to $\theta = 5.5^\circ$ and after the first 25 seconds, the aerodynamic pitching moment is slightly greater than the moment due to nose heaviness, causing the nose to rise slowly to $\chi = -3.2^\circ$. The airship loses height throughout, falling about 11 ft./sec. after $t = 50$. At $t = 130$, she has dropped 1,400 feet.

u increases during the whole of the time under consideration, but the other variables have all attained steady values by $t = 100$. The thrust is considerably greater than the drag at the initial speed, but is nearly balanced towards the end, the continued increase in the later stages being due mainly to the com-

ponent of the weight along the longitudinal axis. The diminished thrust is not sufficient to give the air speed necessary for raising the nose to the horizontal, so that the ship has her nose 3° down in this case, as compared with the equilibrium value of 12° up for Case *E* with the full thrust and greater heaviness.

The elevators have been kept amidship throughout.

Effect of Virtual Mass

60. *Case S.*—The conditions governing this case are identical with those of Case *M*, with the exception of the values chosen for the virtual mass corrections. The masses and moment of inertia assumed in the two cases are:—

Case *M*: $m_1 = 7{\cdot}5$, $m_2 = 13{\cdot}9$, $B_1 = 3{\cdot}81 \times 10^5$
Case *S*: $m_1 = 7{\cdot}5$, $m_2 = 11{\cdot}0$, $B_1 = 2{\cdot}90 \times 10^5$

The values of u, w, q, χ, θ, α, are shown by broken lines in Fig. 21 with the values for Case *M*, and the position of the airship every 10 seconds is displayed by crosses in Fig. 22 on the flight path for Case *M*, assuming the ship to be flying against a wind of 40 ft./sec.

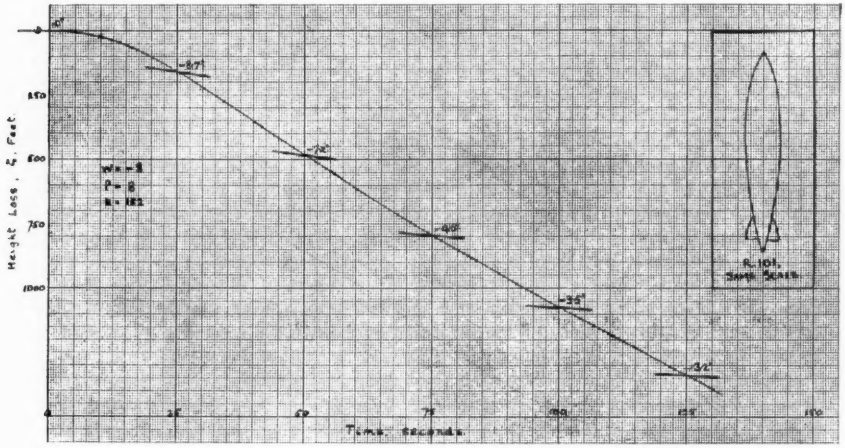


FIG. 31.
Case R. Height loss.

61. When the calculations of various cases for the Court of Inquiry were started, considerable doubt was felt as to the absolute accuracy of the results, owing to the uncertainty in the virtual mass corrections. It was thought, however, that though the actual results might be in error, the order of the results and the general form of the curves would be correct. In order to be consistent the same corrections for virtual mass were used throughout. It was, however, considered desirable to attempt to determine the magnitude of any errors introduced by uncertainties in the virtual mass corrections. A case has therefore been worked out (Case *S*) in which all the conditions of weight, elevator movements and gust, etc., were identical with those governing a previous case (Case *M*), but in which very different corrections for the virtual mass along the transverse axis and for the virtual moment of inertia have been employed. The value of the correction along the longitudinal axis was not altered as it is comparatively small (5 per cent.).

The results for Case S are shown by broken lines in Fig. 21, in which the variables for Case M are plotted as full lines. The position of the airship every 10 seconds for Case S is indicated by crosses in Fig. 22 for comparison with the flight path of the airship in Case M.

As virtual mass affects only the accelerations of the airship, the changes are most pronounced when there are large alterations in the conditions governing the motion. Before the airship encounters the gust at $t=10$, the only marked difference is in the q curve, where the ship with the smaller virtual moment of inertia (Case S) responds more rapidly; but at $t=10$ the values of q for the two cases are almost identical ($q=-0.0124$ and -0.0126 for Cases S and M respectively).

During the gust there is a larger increase in w as a result of the smaller virtual mass used in Case S; at the end of the gust, $w=11.2$ ft./sec. as compared with 10.0 ft./sec in Case M; the corresponding values of θ are 8.9° and 8.0°. The difference in θ causes a noticeable difference in α, χ being almost unaltered. The variation in q during the gust is more marked in Case S than in Case M; it grows more quickly, but also dies away more quickly, and by the end of the gust is smaller in Case S than in Case M; this is chiefly due to the increased aerodynamic righting moment consequent on the increased angle of incidence. The integrated value of q, *i.e.*, the change in χ, during the gust is actually less in Case S than in Case M. After the gust, q changes sign rapidly and swings up to the same positive value in the two cases; but again the change is quicker in Case S.

The more rapid fall in u in Case S is due to the increased drag arising from the greater angle of incidence.

The variables ultimately settle down on parallel paths in the two cases, as the accelerations become very small. The final conditions, being those of a steady state, must necessarily be the same.

Referring to Fig. 22, it will be seen that the crosses defining the flight path for Case S are almost on that for Case M. In the former case the airship loses a few feet more in height during the gust, but afterwards she drops a little less rapidly. Table V gives the positions relative to the starting point in the two cases at various times, assuming the ship to be flying into a head wind of 40 ft./sec.

TABLE V.

COMPARISON OF HORIZONTAL AND VERTICAL DISPLACEMENTS (ξ, ζ) FOR CASES M AND S. DISTANCES IN FEET.

Time (sec.)	10	20	30	40	50	60	70	80	90	100
ξ (M)	415	754	1022	1309	1554	1740	1871	1956	1997	2003
ξ (S)	415	752	1026	1315	1560	1745	1874	1953	1991	1995
ζ (M)	−14	131	407	632	786	857	938	1034	1156	1305
ζ (S)	−11	143	421	635	757	839	918	1015	1139	1290

It will be seen that the differences are very slight; the results show that in this type of motion, great accuracy in the estimation of the virtual mass corrections is not essential.

Conclusion

62. Though the calculations were initiated to assist the Court of Inquiry into the disaster to the airship R.101 in finding possible causes of the accident, the results are of considerable interest quite apart from their first application, in that they demonstrate the behaviour of airships under various assumed conditions. The data of R.101 have been utilised in all cases, but the curves obtained and

the flight paths are applicable to airships in general as regards the form of the curves, the order of the results and the general deductions from them.

The equilibrium of the airship on an inclined path had not been examined when the earlier step-by-step cases were calculated; and it was thought at first that nose heaviness would cause the ship to dive, then that putting up the elevators would raise the nose and the continued loss of gas forward would send the ship into a second dive. The first cases worked out immediately disproved this assumption, and the further cases verified the conclusion that nose heaviness would certainly bring the ship down, but that, after recovery from an initial dive, the ship would descend with her nose well above the horizontal. Further, it was discovered that the greater the gross heaviness of the ship with given forward heaviness, the greater would be the inclination of the axis during the steady descent; or, the smaller the gross heaviness, the more rapidly would the ship dive. This is illustrated by the dropping of ballast. Instead of diminishing the rate of fall, except for a short space of time immediately afterwards, jettison of ballast causes the ship to lose height more rapidly.

Some of these effects were quite unexpected and they demonstrated the need for calculations of this kind. If airship work is revived, it would be of great advantage to calculate the motion of a particular airship under a variety of conditions; especially those which could be carried out experimentally in actual flight, in order to provide a direct comparison with the calculations.

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ABSTRACTS AND NOTICES

FROM THE

SCIENTIFIC AND TECHNICAL PRESS

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(Prepared by R.T.P.)

No. 25. NOVEMBER, 1932

Aircraft Design

Configuration of Air Flow Round an Aeroplane in Flight. (A. Magnan and A. Sainte-Laguë, Pub. Sci. et Tech. du Ministère de l'Air, No. 12, 1932.) (5.1/24801 France.)

A Venturi tube was mounted in a variety of positions, fully shown by diagrams and photographs.

The velocity of the aeroplane was determined by cinematograph records taken through a fixed grid. (Abstract No. 19/21309.) The results are tabulated and plotted and the model wing results of Bryant and Williams (Abstract No. 3/5316) are reproduced for comparison. The general agreement is satisfactory.

Kinematograph Record of Aeroplane Movements. (A. Magnan and A. Sainte-Laguë, Pub. Sci. et Tech. du Ministère de l'Air, No. 9, 1932.) (5.1/24802 France.)

The aeroplane is equipped with a kinematograph, and periodic exposures are taken of marks on the ground. These marks may be ruled squares or triangles, or a polar network of radii and circles, or other geometrical forms of known dimensions. Alternatively records may be made of the landscape for comparison with an ordinary map.

The methods of projective geometry are then applied to deduce the position and altitude of the aeroplane with respect to the known system of reference at regulated intervals of time.

The method is evidently an extremely general one, and the reduction of the aeroplane trajectory in each case depends on the methods of projective geometry. Numerous examples of records are reproduced.

Design of Racing Seaplanes. (G. Pegna, Riv. Aeron., No. 6, June, 1932, pp. 461-516.) (5.13/24803 Italy.)

The various possibilities of reducing head resistance and increasing speed of a rising seaplane are considered comprehensively. A number of original devices are suggested. These are illustrated by sketches for designs and by photographs of experimental machines actually constructed. In one design the wings are directly attached to the hull, while a swivelling airscrew mounting permits the raising of the screw above the surface of the water during the start and its lowering into alignment with the hull axis during flight.

Higher Air Speeds at Less Cost. (S.A.E. Jrnl., Vol. 31, No. 3, Sept., 1932, p. 384.) (5.14/24804 U.S.A.)

Faired lines and a retractable landing carriage improved the cruising speed of a commercial aeroplane by 50 per cent. for the same load and power. The saving per ton/mile is proportional to the increase of speed on a running cost of 25 dollars per hour for both old and improved types.

Factors which Influence Insurance Rates. (J. Lederer, Aeron. Eng., July-Sept., 1932, pp. 117-122.) (5.14/24805 U.S.A.)

The principal factors are grouped under headings:—

1. The design of the aircraft.
2. Operation and management.
3. Pilot.
4. Geographical location.
5. Nature of operations.

Under these headings the usual structural and performance items of aircraft and power plant are briefly discussed in a series of paragraphs under appropriate headings, such as "Landing Speed," "Climb," etc., "Fire Extinguishers and Screens," etc. An increase in structural failures from 1929 to 1930 is attributed to the rapid output of untried designs during the boom.

Civil Aviation in Turkey. (Luftwacht, No. 4, April, 1932, p. 122.) (5.14/24806 Germany.)

The Curtiss Corporation of America has acquired the former Junkers factory at Kaisserije and is organising civil aviation in Turkey. The contract with the Government is for a period of five years and was obtained in the face of active European competition by the financial strength of the American concern.

Air Transport in all Countries. (M. Wronsky, Z.F.M., Vol. 23, No. 12, 24/6/32, pp. 334-341.) (5.14/24807 Germany.)

A general survey is given of the development of air transport, including inter-Continental schemes. Two maps of the world show (*a*) existing and principal projected air routes, (*b*) air routes lighted for night flying. The latter map shows the predominance of the United States services in this direction. European lighted routes are mostly in Northern France and Germany. Two considerable stretches along the trans-Siberian Railway are indicated on the Moscow, Kasan, Omsk sectors. Graphical methods are used to exhibit the volume of traffic in various countries.

A table gives details of the aeroplanes and engines used on the principal routes.

Aeroplane Production for America. (Autom. Absts., Vol. 10, No. 9, Sept., 1932, p. 365.) (5.14/24808 U.S.A.)

The figures of aeroplane production in the United States for the first six months of 1932 are:—

351 civil, 325 military, 46 for export.

Classification of civil aeroplanes shows:—

264 monoplanes, 71 biplanes, 16 autogiros.

The Value of Weight Saving in Aeroplanes and Engines. (E. P. Warner, Aviation, Sept., 1932, pp. 382-384. See also Airc. Eng., No. 45, Nov., 1932, pp. 289-290.) (5.14/24809 U.S.A.)

The average overall value of weight saving in commercial aircraft is stated to be 8 dollars per lb. for the engine and 11 dollars per lb. for the aeroplane structure under present conditions.

The method of analysis is necessarily rough, but the line of argument is worth consideration.

Bombers and Civil Transport. (Sci. Am., Vol. 147, No. 4, Oct., 1932, p. 236.) (5.14/24810 U.S.A.)

The interchangeability of bombing and civil transport aircraft is illustrated by the ready conversion of the Boeing bomber into a high-speed trans-continental passenger aeroplane. The following figures are given:—

Total weight, 12,000 lbs.	Max. speed, 175 m.p.h.
Cruising speed, 155 m.p.h.	Ceiling, 18,000 ft.
10 passengers.	500 lbs. mail.

Blériot Multi-Seater Fighter. (L'Aeron., No. 158, July, 1932, pp. 199-204.) (5.15/24811 France.)

Photographs exhibit the arrangement, and sketches give a number of details, of construction of wings and frame of the Blériot 5½-ton multi-fighter.

The field of fire is delimited by a pencil of rays touching the obstructing surfaces and forming an irregular cone. The intersections of this cone with the sides of a cube are reproduced as a representation of the field of fire. This representation gives serious distortion in size and shape. (See Abstract No. 20/22151.)

Distribution of Pressure on Biplane Wings. (R. W. Noyes, N.A.C.A. Rept., No. 417, 1932.) (5.2/24812 U.S.A.)

The biplane wings were mounted on a rotating circular disc sunk in a plane surface forming a complete chord of the tunnel section. Leads from 120 orifices were taken to a multiple manometer, from which records were made on sensitised paper by a beam of light. Lift-incidence curves were measured for different staggers, gaps and angular settings.

The rolling moment due to roll was recorded for different gaps and staggers. The effect of stagger, gap, angular setting and dihedral and sweep-back on the pitch moment were observed. A mass of results is recorded. Forty tables and 53 diagrams are given.

Diminution of Lift of Aerofoils by Resistance. (A. Betz and J. Lotz, Z.F.M., Vol. 23, No. 10, 28/5/32, pp. 277-279.) (5.2/24813 Germany.)

The author notes that in the two-dimensional problem in a perfect fluid a wing of appropriate circulation develops a lift (proportional to the product of velocity and circulation) and no drag. He proposes to imitate the phenomena by a distribution of sources on the back of the wing towards the trailing edge with a corresponding distribution of sources on the circle from which the wing is derived by conformal transformation. The falling off of theoretical lift in a perfect fluid is compared with the increase of resistance for variations of the usual parameters in the Joukowski transformation and with experimental curves obtained by Wieselsberger. (The fit is not very satisfactory and it is difficult to see how the introduction of additional sources can be the basis of a satisfactory physical theory, in spite of the fact that it produces head resistance and a decrease in the circulation required to give smooth flow at the tail.)

Estimation of Profile Drag. (W. R. Andrews, Flight, Vol. 24, No. 25, 17/6/32, pp. 530a to 530d.) (5.2/24814 Great Britain.)

The author uses chiefly N.A.C.A. data obtained in the high density channel to separate induced drag from total drag. Curves of lift at minimum profile drag are prepared for the use of designers.

Nine references are given in Part I.

The Hall High-Lift Wing. (F. E. Weick and R. Sanders, N.A.C.A. Tech. Note, No. 417, May, 1932.) (5.2/24815 U.S.A.)

The Hall high-lift wing is an application of the same principle as in the succeeding abstract. Similar results are obtained, namely, a large increase in maximum lift and a shift backwards of the centre of pressure.

A photograph of the model exhibits a gap along the whole span in the forward part of the under surface and a flap fitting into the after part of the under surface and mould downward, on hinges pivoted forward of the leading edge of the flap, so that a species of slot is formed. Eighty per cent. increase of maximum lift is obtained, with a shift backward of the centre of pressure. Structural difficulties are not discussed.

Theory of Wings with Cut-Away Portions. (J. Lotz, Z.F.M., Vol. 23, No. 14, 28/7/32, pp. 410-413.) (5.2/24816 Germany.)

Measurements by Ackeret and Muttray show the unfavourable influence of cut-away parts of the wing plan. A cut-away forward increases the induced resistance, and a cut-away aft increases the profile resistance. Muttray has also shown that by adopting suitable high-lift profile, where the chord is decreased by the cut-away, the unfavourable effect can be reduced to small proportions. Starting with an elliptical contour for an uncut wing the cut-away produces a dip in the curve of lift distribution. A new elliptical lift distribution is drawn touching the bottom of the dip and leaving by subtraction two small approximately elliptical distributions of lift separated by a gap. A somewhat elaborate analysis is introduced for dealing with the lift thus resolved. Approximate formulæ of transformation are developed and plotted for rapid numerical use, and the results are applied to three wing profiles. The measured and calculated changes of lift are compared graphically and show the same general run. The discrepancy in magnitude does not exceed what might be expected.

Characteristics of a Wing with a Movable Aileron. (F. E. Weick and T. A. Harris, N.A.C.A. Tech. Note, No. 422, May, 1932.) (5.2/24817 U.S.A.)

The hinge of the aileron is mounted so as to be slidable towards the rear edge of the fixed plane, thus in effect increasing the chord of the wing. The hinged aileron or flap extends along the whole span of the wing. The dimensions of the wing were 60 ins. span by 10 ins. chord, and the maximum chord width of the flap was 4 ins. The maximum lift was increased and the centre of pressure shifted backwards, but the increase of lift, over 100 per cent. in the extreme case, is perhaps larger than might have been expected. Extensive data are given graphically and in diagrams for three values of flap width—20, 30 and 40 per cent. of the chord—and for six angular settings increasing from 0° to 60°, by uniform steps, and for main plane incidence from $-15°$ to $+30°$.

Development of Aeroplane Wing Construction. (C. Topfer, Z.V.D.I., Vol. 76, No. 12, 19/3/32, pp. 281-286.) (5.25/24818 Germany.)

A lucid summary is given of the mechanical problems common to all types of wing structure and the advantages and disadvantages are considered for each case.

The monoplane has a comparatively small girder depth and high spar moments which is partially met by use of deep profiles and clean construction. In large aeroplanes full use must be made of every available device, to offset the increase of weight with linear dimensions for similar structures—such as utilisation of the interior space of the wings, allotment of a share of the linear stresses to the wing covering, design of wing nose for torsional stiffness, etc.

Approximate Calculation of Multi-Spar Wings. E. Sanger, Z.F.M., Vol. 23, No. 9, 14/5/32, pp. 245-250.) (5.25/24819 Germany.)

The author indicates a systematic method of determining the stresses in multi-spar wings. The framework of the wings is indicated graphically along with assumptions made as to the distribution of the loads. The method can be applied to wings pivoted at the centre and cantilever wings with directly or indirectly loaded ribs.

Account can be taken of the systematic errors introduced by the arbitrary assumptions. No numerical example is worked out, but influence lines are reproduced for the last case considered.

Calculation of Strength of Wing Struts under Air Forces. (E. Amstutz, Z.F.M., Vol. 23, No. 13, 14/7/32, pp. 374-376.) (5.3/24820 Germany.)

The lift and drag curves are resolved into tangential and normal force curves. Graphical methods are developed to facilitate the rapid calculation of the air force bending moment and fixing moment of the strut. A numerical example is worked out.

Five references are given.

Experiments on Ailerons Rigged 10° up in the Symmetrical Position. (F. E. Weick and C. J. Wenzinger, N.A.C.A. Rept., No. 423, 1932.) (5.31/24821 U.S.A.)

Ailerons thus rigged increase the drag and decrease the lift of the wing. When operated, upward motion further increases the drag and decreases the lift, while downward motion increases the lift and decreases the drag. In this way the rolling moment is increased by the yaw set up by the concomitant yawing moment.

A number of measurements were carried out on ailerons of three different sizes with the usual equal and opposite motion and with three differential motions. The results are tabulated and shown graphically.

Streamline Wires; Effects of Corrosion. (H. E. Haven, Aeron. Eng., July-Sept., 1932, pp. 109-115.) (5.42/24822 U.S.A.)

It is considered that the most serious excess stresses imposed on streamline wires are due to torsional oscillations set up by the relative air stream. A number of sections of streamline wire were submitted to alternating torsional stresses. Tables give the chemical composition of the materials used and the results of simple tensile tests and of fatigue tests. The latter are also shown graphically. Twenty-eight photographs of test specimens after failure are shown.

Undercarriages, Floats and Hulls

Stresses in a Wire Wheel with Non-Radial Spokes. (A. J. Sutton-Pippard and Miss M. J. White, Phil. Mag., No. 90, Aug., 1932, pp. 210-233, and No. 91, Sept., 1932, pp. 436-445.) (5.5/24823 Great Britain.)

The wheel is constructed so that the spokes are tangential to hubs of appreciable dimensions compared with the wheel itself. Differential equations are formed in terms of the radial and tangential strain with the polar angle as

independent variable. The tangential strain is eliminated, leaving a differential equation of the sixth order with constant coefficients soluble in terms of elementary functions. Numerical examples are worked out fully and the results are exhibited in tables and in graphical diagrams showing the spoke tensions, bending moments on the rim, maximum stress and position of maximum. A correcting term is introduced for the case in which the spokes are not in the plane of the rim but are splayed outward at a small angle.

In Part 2, expressions are worked out for stresses imposed by side loads on the rim, and numerical results are exhibited graphically and in tables.

Shock and Gliding Stresses on Hydroplane Surfaces. (H. Wagner, Z.A.M.M., Vol. 12, No. 4, Aug., 1932, pp. 193-215.) (5.51/24824 Germany.)

The author deals systematically with problems scattered through a number of previous papers. The methods of mathematical hydrodynamics are applied with assumption as to boundary conditions set up by the displacement of the water surface, which are probably good approximations to the actual facts. Applications are made to typical float surfaces under various landing conditions, and analytical expressions are obtained in a form suitable for application. No numerical examples are worked out.

Forty-two references are given.

Dimensions of Pneumatic Tyres for Aircraft. (F. Michael, Z.F.M., Vol. 23, No. 13, 14/7/32, pp. 377-390, 280th Rept. D.V.L.) (5.55/24825 Germany.)

The introduction of balloon tyres in America has increased greatly the number of stock sizes required.

An elementary theory is developed, and numerous test results are reproduced showing the relation between pressure increase and deformation of tyre. Photographs show the deformation caused by passing over obstructions in the shape of bars 20 and 40 mm. in height and the corresponding measurements are plotted graphically for different positions of wheel in relation to the obstructions. A number of secondary influences are also considered in some detail, including the application of brakes. A scheme of standardisation is suggested, specifications being given in a table and in dimensioned sketches for eight sizes of balloon tyres.

Landing Tests on Aeroplanes. (G. A. Guglielmetti, Riv. Aeron., No. 7, July, 1932, pp. 26-60.) (5.55/24826 Italy.)

The methods of suspending and dropping aeroplanes are shown in diagrammatic sketches. An aeroplane is shown mounted in an ingenious suspension whereby alternating loads may be imposed approximating to those met with in operation. The object of the system of tests proposed is to establish a basis for granting certificates of structural strength.

Airscrews

Experiments on Airscrews of Different Pitch. (A. Faraboschi, Aeron. Lab., R. School of Engineering, Turin, L'Aerotecnica.) (5.6/24827 Italy.)

Measurements were carried out from large negative to large positive ratios of rotation to axial motion. The characteristic curves are of interest to designers —particularly for small negative ratios.

Airscrews and their Adaptation to Aircraft. (R. Pris, L'Aérophile, June, 1932, pp. 177-181.) (5.6/24828 France.)

Reference is made to six American and two British Government publications. The author points out that the design of airscrews remains semi-empirical and that further study of air flow round airscrew blades is required before a physical theory can be developed. He does not make it clear that the real difficulty lies in the intractable nature of the problems of turbulent flow.

Effect of Position of Airscrew and Fairing with Reference to Thick Wings. (D. H. Wood, N.A.C.A. Rept., No. 415, 1932.) (5.61/24829 U.S.A.)

Full-scale tests were carried out on the effect of airscrew position on performance. Nine positions are shown with the engine above the wing, three with the fairing of the engine running into the wing, and nine with the engine below the wing.

The tests were carried out at full scale in the large wind channel, dimensions and positions being specified numerically. The formulæ of reduction are stated, and a mass of results is given in twelve tables.

In a diagram the 21 positions are shown in the plane of symmetry and iso-efficiency curves are drawn showing a maximum of 80 per cent. with the engine and nacelle in the extreme position below and in front of the wing nose and 79 per cent. for the extreme position above and in front. Iso curves of equal drag factors and net efficiencies at different speeds are drawn.

The best location for airscrew and fairing is in line with the centre of the wing at 25 per cent. of the chord forward.

Six references are given.

Airscrew Vibrations. (F. Liebers, Z.F.M., Vol. 23, No. 9, 14/5/32, pp. 251-259, 274th D.V.L. Report.) (5.63/24830 Germany.)

Rayleigh's principle is applied to reduce the numerous parameters of the airscrew to two, *viz.*, the observed static bending frequency and the ratio of the rigid hub diameter to the airscrew diameter. An empirical formula is given which expresses the natural frequency in rotation as a function of the angular velocity. Numerical values are shown graphically for a range of hub diameters and angular velocities. The boundary and the influence of curvature are discussed. Experimental apparatus is described and illustrated by a diagram. A photograph shows the stroboscopic mirror, and stroboscopic photographs are reproduced from the film camera. The vibrations observed by this method are plotted graphically and exhibit generally damped oscillations, but in one case the amplitude appears to be increasing. The empirical equation is compared graphically with the observed results and excellent fits are obtained.

Eight references are given.

The Study and Design of Airscrews. (M. Volpert, Revue Générale de l'Aéronautique, No. 14, 1932, pp. 151-156.) (5.658/24831 France.)

Various metal designs are described, including the Ratier and Blériot. Variable pitch is of advantage during the start to flying boats, since the resistance passes through a maximum value and a relatively small increase in thrust may determine successful lift.

Wind Power Stations. (Z.V.D.I., Vol. 76, No. 38, 17/9/32, p. 923.) (5.67/24832 Germany.)

An ambitious proposal is made for wind-driven electric generating stations of 100,000 kw. output, the units being A.C. generators driven by airscrew of 160 m. diameter and 15 r.p.m. maximum speed, mounted on towers 240 m. high.

Instruments

Engine Synchroniser. (Aero Digest, Vol. 21, No. 1, July, 1932, p. 54.) (6.48/24833 U.S.A.)

Objectionable sound beats are set up on multi-engined planes unless the engine revolutions are closely synchronised. A convex mirror on the cowling of each outboard engine enables the pilot to look through the outboard airscrews to the centre airscrew. A stroboscope effect is obtained and exact synchronisation is shown by a stationary range.

Elementary Theory of the Gyroscope. (P. L. Tea, Jrnl. Franklin Inst., Vol. 214, No. 3, Sept., 1932, pp. 299-325.) (6.52/24834 U.S.A.)

A useful summary is given of the elementary mechanics of the subject illustrated by clear diagrams. The analysis is reduced to the simplest terms in the examples considered.

Double Horizon Sextant. (Z.F.M., Vol. 23, No. 9, 14/5/32, p. 273.) (6.52/24835 Germany.)

A note is given on a double horizon sextant. Both horizons are brought into the field of the telescope and remain in the same relative position when the sextant is moved.

Types of Acoustic Sounding Apparatus. (Z.V.D.I., Vol. 76, No. 35, 27/8/32, pp. 847-849.) (6.62/24836 Germany.)

Types of shipboard sounding apparatus are described, including the Behm apparatus.

The echometer records depths by a pointer set on a dial at 15-second intervals, in correspondence with the number of impulses emitted.

The British Admiralty apparatus gives a graphical record at 4-second intervals.

The effective range is from 3 metres to 1,000 metres, the latter depending on the feasible amplification. The best results are obtained at about 160 metres.

For small depths a sinker, with substantially constant rate of descent, is dropped overboard and on its striking bottom a small charge is detonated. The depth is estimated from stop-watch readings of the time of descent. The method is simple and accurate.

Echo Sounding from Aircraft. (C. Florisson, Comptes Rendus, 194, 4/4/32, pp. 1149-1150.) (6.62/24837 France.)

A high speed chronometer pointer completes a revolution in 1/5 sec. A magnetically controlled air valve emits very short sounds of high pitch at intervals corresponding to about 7 or 8 turns of the pointer.

The sound is directed towards the earth by a conical reflector and the echo is received by a similar reflector. The time interval is estimated by eye on the chronometer dial. Aeroplane heights have been determined in this way from 10 m. to 240 m.

Stability and Control

The German Airworthiness Test. (Luftwacht, No. 8, August, 1932, p. 317.) (7.10/24838 Germany.)

The German rules give latitude to the manufacturer with the object of fostering new designs. There are special regulations for gliders, of which there are 1,500 in Germany against 900 power aeroplanes.

Stability of an Aeroplane Running on the Ground. (E. Anderlik, Z.F.M., Vol. 23, No. 10, 28/5/32, pp. 280-285.) (7.2/24839 Germany.)

A diagram shows the air forces and the reactions at the point of contact of the wheel with the ground in equilibrium with the weight and the thrust of the screw. The equations of motion are formed in a manner quite analogous to the ordinary equations of fore and aft stability in the air and the solution proceeds along similar lines. Five criteria of stability are obtained in appropriate form. A numerical example is worked out for specified aeroplane data, and the results are plotted for different values of the coefficient of rolling friction and of various parameters.

D.V.L. Gliding-Angle Control. (B. W. Hubner, Z.F.M., Vol. 23, No. 15, 12/8/32, pp. 455-459, 283rd D.V.L. Rept.) (7.30/24840 Germany.)

The control consists of two vertical fins of symmetrical profile fitted in the upper surface and rotatable about vertical axes in opposite directions. The profile is normally parallel to the direction of flight, but in gliding the fins can be rotated outwards across the line of flight and destroy the smooth flow over the upper surface. A decrease of the lift coefficient and an increase of the gliding angle are obtained. Test results are given graphically and show that the range of descent from 100 m. at a speed of 90 km. per hour can be reduced from 735 m. to 440 m. The pilot gains a corresponding flexibility in selecting his landing point without increasing his flying speed.

Landing Speeds, Monoplanes—Effect of Airscrews and Nacelles. (R. Windler, N.A.C. Tech. Note, No. 420, May, 1932.) (7.3/24841 U.S.A.)

The positions of engine and nacelle affect both lift and drag. The relevant results are contained in diagrams showing the effect of position on the lift coefficient. In the most unfavourable position the lift coefficient is seriously reduced and the landing speed is correspondingly raised. The changes in drag coefficient have a negligible effect on landing speed.

Automatic Stability. (Fr. Haus, L'Aéron., No. 159, August, 1932, pp. 243-251.) (7.50/24842 France.)

From author's abstract.—In the first part the author discusses longitudinal stability in the usual manner and shows that the stabilisation of all motion simultaneously is impossible.

In the second part derived types of partial automatic stability are discussed, each based on a particular motion of stability:—

(*a*) Etévé, stabiliser depending on variations in flying speed;
(*b*) Etévé, Constantin, depending on change of instruments;
(*c*) Sperry, depending on general angular position;
(*d*) Lucas, Girardville, depending on angular velocity.

The author proposes to use the apparent direction and magnitude of gravity.

A brief discussion of more complex types of stabiliser is given.

Spinning of Aircraft. (G. G. Budwig, Aeron. Eng., July-Sept., 1932, pp. 79-81.) (7.62/24843 U.S.A.)

The author, who has had extensive test experience, discusses the introduction of spin tests into airworthiness requirements. Test data and adjustments are given, such as times of spirals in irregular spins, shifting of engines and wings, placing of weights, etc. Statistics are given from 1927 to 1930 of accidents due to spinning, with the percentage falling from 3.5 to 2. Four conditions are laid down for satisfactory spin characteristics:—

(*a*) Stability about all three axes.
(*b*) C.g. well forward of c.p.
(*c*) Wing loading kept below the appropriate maximum.
(*d*) Concentration of weights near c.g.

Airflow about the Tail in a Spin. (N. F. Scudder and M. P. Miller, N.A.C.A. Tech. Note, No. 421, May, 1932.) (7.62/24844 U.S.A.)

A description is given of the aeroplane used and of the titanium tetrachloride smoke generator installed. Fourteen photographs exhibit the flow of the smoke in a spin.

Ordinary Spin and Flat Spin. (Delbègue, Rev. F. Aer., No. 35, June, 1932, pp. 655-702.) (7.62/24845 France.)

A careful summary is given of the present position of knowledge on the subject of the spinning of aeroplanes. The methods applied and the results obtained in various countries are briefly referred to.

Twenty-four references are given.

Investigation of the Spinning Properties of the Focke-Wulf A.32 "Buzzard." (H. D. Knoetzsch, Z.F.M., Vol. 23, No. 12, 24/6/32, pp. 356-357, 285th D.V.L. Report.) (7.62/24846 Germany.)

A specification is given of the aeroplane and a description of the instrument installation. A descriptive account is given of the forced motion with the c.g. at 30, 32.4, 34.6, 37, 38.8 per cent. of the chord behind the leading edge. The positions in front of the ailerons are also specified. It was only with the c.g. at the farthest back position (38.8 per cent.) that a spin could be developed, which lasted for three turns only. A graphical diagram shows the turning angle as a function of time. The spin was developed in about $5\frac{1}{2}$ seconds, the time of a complete turn of 360° being about 3.4 secs. The vertical descent was 25 m. per sec.; the inclination of the longitudinal axis was estimated at $-70°$ to $-80°$.

Suggestions for further systematic tests are added.

Handley Page Ailerons with Automatic Slots; Flight Measurements. (W. Pleines, Z.F.M., Vol. 23, No. 10, 28/5/32, pp. 287-296, 279th D.V.L. Report.) (7.72/24847 Germany.)

Dimensioned sketches show the details of plan form and section of the ailerons and slots and a photograph shows the Albatross L. 75 thus fitted. Details are also given of wing tip water ballast tanks capable of rapid discharge and correspondingly rapid setting up of a rolling moment. Records made in flight are given graphically and show lift as a function of incidence for full power and for a throttled engine, polar curves with and without slots opened, and incidence as a function of dynamic pressure.

The flow of the air over the lower wing is indicated by trailing threads and three groups of twelve photographs are reproduced showing the direction of the threads and approximately of the wind. Observed rolling moments are recorded graphically against time.

Without slots all tests exhibited a sudden drop of one wing beyond a definite incidence accompanied by loss of damping of the rolling motion. In every case the resulting attitude was dangerous. Accompanying phenomena are also described.

With slotted ailerons the incidence of maximum lift was increased by about 8°, and sufficient damping of the rolling was maintained. No tendency of the wing to drop was observed. The satisfactory results appear to be entirely due to the effectiveness of the slotted ailerons.

In certain cases a periodic rolling motion followed the initial disturbance, and in these cases a satisfactory stabilising effect was observed and was ascribed to the slotted ailerons.

Blind Landing. (M. H. Gloeckner, Z.F.M., Vol. 23, No. 12, 24/6/32, pp. 347-356, 284th D.V.L. Report.) (7.8/24848 Germany.)

The author states fully the special problems of blind landing and surveys the extensive development, particularly in radio beacons.

Long-range directional beacons are applied to give the general direction of the aerodrome sought, special code signals designating each station.

Having reached the neighbourhood of the aerodrome, short-range beacons are applied to give the exact landing direction and the angle with the horizontal at which the aircraft should approach the actual landing ground.

Other methods of determining the height above the ground are discussed, giving micro-barograph observations, determination of height by reflection of sound, by alteration of electrical capacity and by the strength of the magnetic field of a leading-in cable.

Brief descriptions are given of apparatus applied with diagrams of field direction and intensities, examples of signal strengths, diagrams of connection and photographs of ground and aeroplane apparatus.

Thirty-one references are given.

Engines—Thermodynamics

Combustion of Hyd-o Carbons. (W. A. Bone, Proc. Roy. Soc., Vol. 137, No. A.832, 2/8/32, pp. 243-274.) (8.13/24849 Great Britain.)

A satisfactory theory of combustion should deal adequately with the whole range, from slow combustion through high pressure flames, and explosions to detonation.

The hydroxylation theory developed by the author receives quantitative confirmation from the isolation of intermediate products. The peroxide theory advanced by workers mainly concerned with slow combustion phenomena is considered to lack sufficient experimental confirmation. Inferences drawn from observed pressure time records, or from response to potassium iodide solution under condition of slow combustion, are found unreliable and misleading when compared with authenticated explosion and detonation phenomena.

New Thermo Couple for High Temperature. (Z. Metallk., Vol. 24, No. 6, June, 1932, p. 126.) (8.14/24850 Germany.)

An alloy of platinum with 4.5 per cent. rhenium and 5 per cent. rhodium gives a thermo-electric potential of 20 millivolts at 1,000° and shows greater metallurgical stability up to 1,600°C. than the alloy of platinum with 8 per cent. Re.

Application of Rare Metal to Thermo-Electric Pyrometers. (Z. Metallk., Vol. 24, No. 6, June, 1932, p. 126.) (8.14/24851 Germany.)

The le Chatelier thermo couple platinum against platinum + 10 per cent. rhodium has long held its place in pyrometric measurements up to 1,600°C. (m.p. of platinum 1,750°C.). The recently-discovered rare metal rhenium (*Nature*, 1930, *et fol. seq.*) finds similar application.

Platinum alloys containing 8 per cent. rhenium, or 4.5 per cent. rhenium and 5 per cent. rhodium, have suitable physical properties and are more stable at high temperatures.

The thermo couples rhodium against a platinum-rhenium alloy, and rhodium against a rhodium-rhenium alloy, are effective up to 1800°, at which temperature they show 20 millivolts and 7 millivots respectively.

Design

Future Aero Engine Development. (C. L. Lawrence, S.A.E. Vice-President, S.A.E. Jrnl., September, 1932, p. 15.) (8.20/24852 U.S.A.)

The four-stroke spark ignition engine with volatile fuel holds the field at present, with possible further developments in scavenging and supercharging by auxiliary blowers and in fuel pump injection into the induction pipe or directly into the engine cylinder. The oil injection engine is still too heavy for aircraft, though the Junkers two-stroke opposed piston engine shows a substantial reduction of weight.

Indicators as a Means of Improving Aircraft Engine Performances. (F. L. Prescott, S.A.E. Jrnl., September, 1932, pp. 361-370.) (8.22/24853 U.S.A.)

A modification of the Juhasz sleeve valve sampling indicator has a mushroom valve, spring loaded and pressure balanced, operated by cam and rocker arm. The design details given are insufficient for critical judgment.

Diesels, etc., and Accessories

A New 4-Stroke Ship's Diesel Engine. (H. Rohwer, Z.V.D.I., Vol. 76, No. 28, 9/7/32, pp. 677-678.) (8.25/24854 Germany.)

The engine has four cylinders with direct injection, 280 mm. bore, 420 mm. stroke and is rated 265 h.p. at 428 r.p.m. The fuel valve needle is lubricated by a small fuel leak along the stem, the excess fuel being returnd to waste. The r.p.m. can be varied through a wide range by hand control of the quantity of fuel and the beginning of injection. A servo-motor controlled by oil pressure ensures response. Mean fuel consumption is 170 gm. per b.h.p. hour at B.M.E.P. 80 lbs. per sq. in. The exhaust remains clear up to B.M.E.P. 100 lbs. per sq. in.

Diesel Engine—Exhaust Gas Temperatures. (Autom. Eng., Vol. 22, No. 297, Sept., 1932, p. 420.) (8.25/24855 Great Britain.)

A pyrometer fitted to each cylinder exhaust renders possible the equalisation of exhaust temperatures, which gives smoother and more reliable running. Failure of the cooling water supply is indicated immediately, and consequent damage to valves is avoided. The error in any pyrometer should not exceed $\pm 5°C$.

The New Michel Engine. (A. Nagel and O. Holfelder, Z.V.D.I., Vol. 76, No. 35, August 27, 1932, p. 839.) (8.292/24856 Germany.)

This engine has no relation to the Michel swash-plate engine.

It is an opposed piston engine which differs from the well-known Junkers two-piston design by possessing three pistons radiating symmetrically from a common combustion chamber of star shape.

The pistons operate three crankshafts placed at the outer extremities of the star and are intergeared by a link plate. Like the Junkers, the two-stroke cycle is adopted, two pistons governing the scavenging ports placed in two of the cylinders whilst the third piston controls the exhaust port in the third cylinder. A positive scavenging pump is fitted. It is claimed that with the three pistons more latitude in the port operation is given without sacrificing working stroke. The published results of fuel consumption and B.M.E.P. are, however, not very different from that of an engine of orthodox design. The maximum pressure employed exceeds 1,000lbs. per square inch. Neither the compression ratio not the weight of the two test engines (40 and 60 h.p. output at 2,000 r.p.m.) is given. It appears essential to employ small cylinders to prevent overheating of the pistons. The h.p. per " star " is limited to approximately 30, larger output being obtained by using a number of " stars " placed one behind the other and operating on the same three crankshafts. On account of the uneven distribution of power between the three pistons, a flywheel has to be fitted. This necessarily entails a considerable number of working parts and must produce high manufacturing costs.

Gas Turbines. (Z.V.D.I., Vol. 76, No. 37, Sept. 10, 1932, p. 895.) (8.296/24857 Germany.)

An application of the gas turbine is proposed in conjunction with steam power. The combustion chamber becomes the boiler of the steam plant, the

high pressure and temperature of combustion giving high thermal efficiency and compact design. The partially cooled gases should present less severe difficulties in the design of gas turbines to be run as auxiliaries.

Torsional Oscillations of a 1,500 h.p. Diesel Engine. (H. Baer, Z.V.D.I., Vol. 76, No. 28, 9/7/32, pp. 689-690.) (8.36/24858 Germany.)

The engine has six cylinders and two flywheels, one coupled direct, the other through an elastic leather coupling at the same end of the shaft and driving a dynamo and water brake respectively through leather belts and pulleys. Torsional vibration was measured at the free shaft end of the engine, as the engine came to rest from full speed. Experiments with and without belts and with the coupling disconnected showed that the vibration characteristics of the engine were practically unaffected by the presence of the second flywheel, which was completely isolated by the leather belt and pulley.

Changes in Internal Damping. (P. Ludwik and R. Schenk, Z.V.D.I., Vol. 76, No. 28, 9/7/32, pp. 683-686.) (8.36/24859 Germany.)

The Schenk torsional fatigue testing machine records the hysteresis loops optically during the test. The area of the loop depends on the frequency. Maintenance of steady temperature of the specimen is required to avoid considerable temperature effects. The relation between fatigue limit and ultimate static strength is necessarily complicated.

Journal Bearing Friction in the Region of Thin Film Lubrication. (S. A. McKee and T. R. McKee, S.A.E. Jrnl., Vol. 31, No. 3, Sept., 1932, pp. 371-377.) (8.37/24860 U.S.A.)

In a previous paper—Vol. 20, January, 1927, p. 3—the author described his apparatus for measuring the friction couple of bearings. A large number of measurements is given in the present paper for three lubricating oils with bronze and Babbitt metal bearings, under constant load, at constant speed, etc. The results are tabulated and the graphical representations show very clearly the comparative superiority of Babbitt metal and the improvement due to running in, by postponing the failure of the lubricating film.

The independent variable is non-dimensional ($u \,.\, w/p$), u=coefficient of viscosity ($m \,.\, l^{-1}\, t^{-1}$), w=angular velocity (t^{-1}), p=pressure ($m \,.\, l^{-1}\, t^{-2}$).

Inconsistent units are used, $z = u/100$ is measured in centipoises ($100 \times$ g.c.$^{-1}$s^{-1}), angular speed is given in r.p.m. and pressure in lbs./sq. in.

The author suggests the parameter $u \,.\, w/p^{\frac{1}{2}}$ although he notes that it has dimensions ($p^{\frac{1}{2}}$).

Apart from the necessity of using non-dimensional parameters such empirical methods are rendered superfluous by Osborne Reynolds' full treatment of the problem (Papers, Vol. 2, p. 228).

The experimental results appear to be worthy of similar treatment.

French Engine Accessories. (Collard, Revue Générale de l'Aéronautique, No. 14, 1932, p. 197.) (8.7/24861 France.)

The article deals with carburettors, fuel pumps, magnetos, sparking plugs, starters and wireless shielding. The " Eyquen " plug has a powdered insulator packed inside a mica sleeve, which gives a uniform distribution of internal pressure and prevents local concentrations of stress.

Cooling

Application of Heavisides Operational Method to the Solution of a Problem in Heat Conduction. (S. Goldstein, Z.A.M.M., Vol. 12, No. 4, Aug., 1932, pp. 234-243.) (8.4/24862 Germany.)

The method is applied to three cases:—An infinite plate, an infinite cylinder, and a circular cylinder of finite length. The results are expressed in terms of elementary exponentials, error functions and Bessel functions. Interesting points arising in these applications are discussed.

Heat Transfer. (A Symposium of Papers presented to the V.D.I. Sub-Committee on Heat Research.) (Z.V.D.I., Vol. 76, No. 37, Sept. 10, 1932, p. 895.) (8.4/24863 Germany.)

Experiments on heat transfer in a Diesel engine gave coefficients of heat transfer from piston rings to cylinder wall, from piston through rings to wall and from piston direct to wall as 30,000, 3,000 and 300 kilo-calories/m^2x°C. respectively.

Heat Conduction in Tubes, Non-Uniform Distribution. (A. Konejung, Z.A.M.M., Vol. 12, No. 4, Aug., 1932, pp. 229-231.) (8.4/24864 Germany.)

Expressions are formed in cylindrical co-ordinates for the quantity of heat transferred. Arbitrary distributions of temperature are assumed and the results obtained in the form of Fourier series with arbitrary coefficients. The coefficients are obtained in the usual way to satisfy the boundary conditions. Simplified results are obtained for a particular type of distribution. A numerical example is worked out.

Passage of Air through Radiators with Tubes at Right Angles to the Air Stream. (H. Schmidt, Z.V.D.I., Vol. 76, No. 11, 12/3/32, pp. 275-276.) (8.4/24865 Germany.)

Specifications are given of fourteen radiators and cost and performance are given in tables and in diagrams. Some empirical formulæ are developed for the thermal relations.

Cowling

Engine Cowl Rings. (P. M. Boyd, Aeron. Eng., July-Sept., 1932, pp. 93-101.) (8.426/24866 U.S.A.)

Ten photographs show different types of cowling and ring as fitted to aircraft. A photograph shows the Curtiss anti-drag ring ready for mounting. A graphical chart shows the percentage increase of maximum flying speed with ring, as a function of maximum speed without ring, rising from 2 per cent. at 120 m.p.h. to 14 per cent. at 170 m.p.h. The development of the ring is stated to be independent of work in England.

Five references are given.

Engine Ring Cowlings. (W. H. Evers, Aeron. Eng., July-Sept., 1932, pp. 103-108.) (8.426/24867 U.S.A.)

An elementary descriptive account is given of the aerodynamical principle of the N.A.C.A. or Townend type of ring cowling, illustrated by rough sketches of air flow. A number of test data are tabulated. Three photographs are reproduced showing ring cowlings in position on radial engines.

Fuels, etc.

Non-Poisonous Coal Gas (by Hydrogenation). (Z.V.D.I., Vol. 76, No. 38, 17/9/32, p. 914.) (8.602/24868 Germany.)

An effective catalytic agent has been discovered for the conversion of a mixture of CO and H_2 into CO_2 and CH_4 and is being applied on a large experimental scale by the Berlin Gas Works to the removal of CO from coal gas.

Alcohol Motor Fuels in Europe. (G. Kaltenbrunner, " Facts about Sugar," Vol. 26, p. 67, 1931. Chem. Absts., Vol. 26, No. 10, 20/5/32, p. 2845.) (8.606/24869 U.S.A.)

European alcohol is obtained principally from agricultural products, molasses and sulphite pulp waste liquor.

The last method yields the cheapest alcohol, but at a price which still requires legislation to enforce admixture with light mineral oil fuels.

Testing of Naval Aviation Gasoline. (B. P. Ward and W. P. Sinclair, Jrnl. of Am. Soc. of Naval Engrs., Vol. 44, No. 3, Aug., 1932, pp. 285-297.) (8.64/24870 U.S.A.)

A brief account is given of the considerations which led to the present specification and tests, which are now largely concerned with anti-knock qualities.

The specification is given. Photographs show the bouncing pin knock testing apparatus, the N.A.C.A. Universal test engine and the ageing apparatus for gum determination.

Desirable practical qualities are discussed.

Carbon Formation—Standard Oil Co. Research Laboratory. (Autom. Eng., Vol. 22, No. 297, Sept., 1932, p. 429.) (8.64/24871 Great Britain.)

The carbon deposit in an engine due to the lubricating oil approaches an equilibrium thickness sufficient to raise the surface temperature to the point of complete evaporation of the oil deposit. The deposition is substantially independent of the oil consumption. The thickness depends on the distillation curve of the lubricating oil and can be predicted therefrom.

The " Conradson " carbon number is stated to be unreliable.

Knock Rating of Motor Fuels. (F. H. Garner and E. M. Dodds, Engineering, Vol. 134, No. 3469, 8/7/32, pp. 45-47, and No. 3470, 15/7/32, pp. 60-62.) (8.645/24872 Great Britain.)

The knock rating of fuels is seriously influenced by local hot spots in the cylinder, notably in the exhaust valve. The paper describes modifications applied to a test engine which include a specially designed carburettor for maintaining correct proportions, an improved bouncing pin of reduced mass, improved seating and movement, spark control by neon tube, free from oscillatory discharges, liquid cooling of valves, and other modifications of less immediate importance.

Experimental results on comparative knock values are shown in tables and graphically in diagrams, and enable the designer to estimate the relative anti-knock values of blending with benzol and of adding small quantities of tetraethyl lead over a wide range of temperatures.

Some observed temperatures are given for the cylinder head near the exhaust valve and for the cooling medium. Reference is made to the advantages of oil-cooled pistons.

Fuel Atomisation. (Autom. Eng., Vol. 22, No. 297, Sept., 1932, p. 417.) (8.7/24873 Great Britain.)

The sizes of the drops into which the fuel is sub-divided are recorded by a special film camera, which can be used both for injection and carburettor engines.

Large drops burn incompletely with loss of power and production of poisonous exhaust gases. The consequent loss of fuel is estimated at $1,500,000,000 per annum.

Researches of D.V.L. 1931-32. (Z.V.D.I., Vol. 76, No. 37, Sept. 10, 1932, p. 883.) (8.7/24874 Germany.)

Two single cylinder engines of large dimensions have been installed for fuel injection experiments. A small air-cooled engine has been installed for work on fuels.

Schauffer's ionisation method has been applied to investigation of the processes of combustion in weak mixtures, with a view to determining the most economical running of carburettor engines.

Behaviour of Diesel Fuel Spray. (Autom. Ind., Vol. 67, No. 1, 2/7/32, p. 10.) (8.705/24875 U.S.A.)

The article deals mainly with the characteristics of the Bosch fuel injection pump. The effect of back pressure on discharge is slight, but there is a sensible increase of fuel temperature at high pump speeds.

Exhaust Systems

Acoustic Filters as Silencers. (K. Schuster and M. Kipnis, Ann. d. Phys., Vol. 14, No. 1, July, 1932, pp. 123-128.) (8.721/24876 Germany.)

Acoustic filters may be regarded as partial sound absorbers, and application is made to engine exhaust silencers in the present paper. The elementary relations between the area of the exhaust pipe and the openings leading to the filter are stated. Further relations are deduced and a numerical example is worked out.

On the basis of the physical discussion a silencer was constructed with four high pitch filters in parallel, in accordance with sketches and dimensions specified. It was applied to a 9 h.p. two-stroke cycle engine and the damping was notably better than with the silencer already fitted. In addition there was no sensible throttling of the exhaust gases, as was to be expected from physical principles.

Water Recovery Apparatus for Airships. (C. P. Burgess, Aeron. Eng., July-Sept., 1932, pp. 83-92.) (8.723/24877 U.S.A.)

A photograph is given of the water recovery plant for the U.S.S. " Shenandoah " and sketches give details of the type of condenser fitted to U.S.S. " Los Angeles." Elementary thermal principles are discussed; formulæ are developed and graphical charts illustrate the numerical relations.

A discussion follows.

Armament

The Equipment of Air Forces. (E. P. Warner, Aviation, Vol. 31, No. 9, Sept., 1932, pp. 369-373.) (9.34/24878 U.S.A.)

The development of bombing principles and practice in the U.S.A. is discussed historically with photographs of successive machines and tables of performance, the latest date being 1931. Bombing operations are classified as light and heavy, short range and long range, day and night. Under certain conditions, *e.g.*, attack on a battleship, bridge or modern building, etc., concentration of the explosive in a single charge produces greater damage than a number of smaller charges. This leads to a demand for the large aeroplane carrying heavy bombs containing a large individual charge. At present 2,000lbs. appears to be the limit of the demand in the U.S.A. A comparison is made with practice in European countries.

A further article discusses training machines and system of training, illustrated by eleven photographs of training types (see *Aviation*, No. 11, November, 1932, pp. 440-443).

Protection against Poisonous Gases. (Z.V.D.I., No. 30, Vol. 76, July 23, 1932, p. 736.) (9.47/24879 Germany.)

In addition to helmets and filters special close fitting suits of rubberised cloth, rubber shoes and gloves are required and have been designed for protection against mustard gas and other skin irritants.

The putting on ordinary sale of such articles indicates that civilian gas protection is receiving practical consideration.

Signalling

Voice Projectors. (C. Huey, Jrnl. of Am. Soc. of Naval Engineers, Vol. 44, No. 3, Aug., 1932, pp. 327-329.) (9.66/24880 U.S.A.)

Direct voice communication to pilots in formation on deck, and even to aeroplanes in flight, is rendered possible by a new type of voice projection. The voice-produced currents in a microphone receiver are amplified in the usual way, and these control discharges of compressed air in the throat of a funnel projector. The beam of sound is fairly narrow and has a horizontal range of 3,000 ft. A range of nine miles has been obtained in communicating with an airship at 3,000 ft.

Much greater secrecy is maintained than with radio messages. A photograph shows some details of the new type.

Searchlights. (C. Huey, Jrnl. of Am. Soc. of Naval Engrs., Vol. 44, No. 3, Aug., 1932, pp. 329-331.) (9.67/24881 U.S.A.)

The main improvement is due to advance in design of electrodes.

The old type $1\frac{1}{4}$ in. dia. positive and 1 in. dia. negative carbons gave a $\frac{7}{8}$ in. dia. crater with a maximum usable power of 120 amps. × 60 volts = 7,200 watts, producing 40,000 candle power. The new type electrodes have a hard-baked shell of carbon from anthracite coke and a core of bituminous coke mixed with cerium fluoride. The positive electrode is .63 ins., the negative .433 ins. dia., with a maximum usable power of 150 amps. × 80 volts = 12,000 watts, producing 140,000 candle power. Minor improvements in the optical parts have been made. Photographs of old and new type arcs are reproduced.

Materials—Corrosion, Welding, etc.

The Creep Strength of Metals at High Temperatures and the Effect of Pre-Heat Treatment. (W. Rohn, Z. Metallk., Vol. 24, No. 6, June, 1932, pp. 127-131.) (10.1/24882 Germany.)

Pure iron, nickel and various alloys were tested at temperatures up to 1,200°C. The creep strength at high temperature was increased considerably by previous exposure to a temperature of the same order.

Corrosion. (U. R. Evans, Engineering, Vol. 133, No. 3460, 6/5/32, pp. 550-551, and No. 3463, 27/5/32, pp. 639-641.) (10.125/24883 Great Britain.)

A closely-reasoned survey is given of the present state of knowledge on corrosion, defined as the destruction of materials by chemical action. Although much remains in doubt and controversy, the body of agreed results is so significant that in the author's view a knowledge of chemistry is indispensable to every engineer who has to deal with corrosion.

At high temperatures, direct combination with oxygen is the common form of corrosion—the rate of reaction depending more on the protective nature of

the oxide film rapidly formed than on the reactive nature of the material. For example, aluminium is highly reactive, but the oxide film is self-healing and gives excellent protection.

Local pittings at weak points in the oxide film may cause more rapid and dangerous damage than much more extensive general corrosion, although the total combined oxygen is less.

A protective coat which prevents general corrosion at the cost of producing intense local pitting may do more harm than good. Numerous instances are quoted from experience. Oxygen may act either directly or by a more or less roundabout process of chemical exchanges. The successful use of paints depends largely on the weathering properties of the paints themselves, but the interaction with a small area of corrosion may accelerate the deterioration of the paint greatly and must be studied in conjunction with direct weathering.

The inclusion of salt crystals between paint and metal may greatly accelerate further corrosion. Other inclusions may be harmful, and cleaning of the surface before treatment becomes correspondingly important.

A wide range of examples is given.

The Combating of Corrosion Fatigue by Preliminary Compression. (A. Thum and H. Ochs, Z.V.D.I., Vol. 76, No. 38, 17/9/32, p. 915.) (10.125/24884 Germany.)

Fatigue limits under corrosion are determined by "breathing" of the surface cracks of the material, by means of which a pumping action is exerted. By preliminary compression these cracks are sealed, and increases up to 50 per cent. in the fatigue limits can be observed in notched or drilled materials when the notch is surface rolled under high pressure or the surface of the drilled hole compressed axially.

Arcatom Welding Process. (Z.V.D.I., Vol. 76, No. 28, 9/7/32, p. 19 (adverts.).) 10.14/24885 Germany.)

Langmuir's original suggestion of using the electric arc in an atmosphere of hydrogen has been developed in America, and the patents covering the process are handled in Germany by the A.E.G.

It is claimed that a very high quality weld is produced, both in steels and light alloys, and for materials up to 3 ins. thick.

Welded Tube Structures. (G. Ivanow, L'Aéronautique, No. 159, Aug., 1932, pp. 255-260.) (10.14/24886 France.)

A descriptive account is given of the technique of welding joints in tubular frame structures. Seven photographs and three sketches illustrate different types of joints.

Strength of High Grade Arc Welding. (G. Czternasty, Z.V.D.I., Vol. 76, No. 28, 9/7/32, pp. 679-682.) (10.14/24887 Germany.)

An arc welded boiler of 6m.^{3} capacity was tested to destruction by water pressure. The deformation of the boiler was recorded with gradually increasing pressure and after the burst samples containing parts of the weld were cut out of the material and tested separately. According to regulations the boiler is intended for a maximum load of 29 atmospheres. It actually failed under 150 atmospheres. Both the nature of the break and the behaviour of the test pieces subsequently cut showed clearly that the material had in no way been influenced deleteriously by the process of arc welding.

Spot Welding of Stainless Steel. (J. Geschelin, Autom. Ind., Vol. 67, No. 1, July 2, 1932, pp. 4-6.) (10.14/24888 U.S.A.)

Under the designation of " shot welding " a method of spot welding is described. Short bursts of current are applied to stainless steel which has eight to fourteen times the resistance of carbon steel. For each spot weld a pen inscribes a curved line, the length of the arc being proportional to the energy expended.

The welding apparatus is set by an expert to give the optimum time of current application for each type of weld and nothing is left to the judgment of the routine operator.

Photographs show the apparatus, welded channels tested to collapse and an improved wing rib in conjunction with a previous design.

" Shot-Weld " Construction. (Aero Digest, Vol. 21, No. 1, July, 1932, p. 64.) (10.14/24889 U.S.A.)

The Budd Manufacturing Co.—The Italian rights have been acquired by the " Savoia " Co. and will be applied to the construction of flying boats.

The U.S. Steel Corporation has acquired the rights for the structural steel in buildings.

See previous Abstract.

Calculation of Helical Springs. (O. Göhner, Z.V.D.I., Vol. 76, No. 11, 12/3/32, pp. 269-272.) (10.164/24890 Germany.)

The methods given in Love's elasticity are extended, and approximate formulæ for computation are developed.

Wind Tunnels, Testing Apparatus, etc.

Free-Jet Type Wind Channel, Focke-Wulf Construction Co. (11.1/24891 Germany.)

A full translation of the article by H. Focke, Z.F.M., No. 11, 14/6/32 (see Abstract 24/24082), appears in *Aircraft Engineering*, No. 43, Sept., 1932, pp. 219-220.

Wind Channel. (P. Rebuffet, Pub. Sci. et Tech. du Ministère de l'Air, No. 5, 1932.) (11.1/24892 France.)

A full technical description is given of a wind channel in use by Service Technique, equipped with dynamometer based on the principle of variable electrical capacity. The theory of the apparatus and the calibration are discussed fully. Once the dynamometer has been regulated measurements can be carried out rapidly. The underlying mechanical principle is the extremely small movement of the dynamometer, which has been reduced to from one-tenth to two-tenths of a millimetre. It is stated that a complete polar diagram can be produced by a single observer in ten minutes. A comparison of results with characteristic curves obtained at the Moscow, Göttingen, Eiffel and Sainte Cyr laboratories shows satisfactory uniformity.

Description and Calibration of 10-foot Wind Channel, California Inst. of Technology. (C. B. Milliken and A. L. Klein, Guggenheim Publication, No. 17.) (11.1/24893 U.S.A.)

A full descriptive account is given of the construction and calibration of a 10-foot wind channel, designed in accordance with v. Karman's suggestions and with many improvements introduced by the authors. The ratio of stream energy per second to motive power attains the high figure of 5.5 at full speed. This is ascribed to a combination of design details of which seven are cited.

An account is given of the calibration of the flow in the test section, including measurements of resistance of spheres as a check on initial turbulence in the flow. Results are excellent. Certain discrepancies raise interesting questions.

A brief survey is given of test work on international models of dirigibles and of aerofoils.

Eight German and American references are given.

Special Methods of Testing Aircraft Materials. (D. M. Warner, Aeron. Eng., July-Sept., 1932, pp. 141-149.) (11.4/24894 U.S.A.)

The equipment and methods of testing at the Wright Field are described and illustrated by photographs of the apparatus and diagrams of the test results. These include combined bending and torsion tests of beams, stress and strain tests of wing ribs, fatigue tests of tubes and streamline wires, Brinell hardness, etc. An apparatus, consisting of a furnace and extensometer for tests at high temperatures is shown in a photograph, and test results from room temperatures to 600°F. are reproduced.

The Duroscope. (O. Schwarz, Z. Metallk., Vol. 24, No. 4, April, 1932, pp. 93-94.) (11.4/24895 Germany.)

A pivoted steel hammer carrying a hardened steel ball at the point of impact is allowed to fall through an arc of known angle, and the hardness is measured by the height of the rebound, which is indicated by a needle on a graduated scale. Correlations between the hardness thus measured and the Brinell hardness are given graphically.

Standardisation of Notch Impact Tests. (M. Moser, Z.V.D.I., Vol. 76, No. 11, 12/3/32, pp. 257-261.) (11.4/24896 Germany.)

The effect of size and shape of the notch is discussed from the point of view of international standardisation. Eight photographs of fractured specimens are reproduced and some correlation curves are given. The test conditions specified in various countries are given with dimensioned sketches.

X-Ray Examination of Materials at the D.V.L. (K. Matthaes, Z.F.M., Vol. 23, No. 15, 12/8/32, pp. 459-466, 292nd D.V.L. Rept.) (11.47/24897 Germany.)

A specification is given of the electrical apparatus for generating suitable X-rays. The testing cabin is 5 m. by 6.2 m. and is shown in sketches of plan and elevation. A photograph of the installation is reproduced. Examination of castings of cast iron, U-girders of cast electron, aluminium alloy castings, cores, etc., is discussed and photographs are reproduced. Methods of welding are also discussed and X-ray photographs of specimens are given. It is concluded that the method is well adapted to examination of completed structural parts and should find increasing use.

Valve Inspection. (Aero Digest, Vol. 21, No. 1, July, 1932, p. 54.) (11.47/24898 U.S.A.)

The General Electric X-ray Corporation have developed a stereoscopic X-ray camera for investigating flaws in aircraft valves.

X-Ray Investigation of Welded Joints. (N. Lefring, Material-prüfungsanstalten, No. 10, Nov., 1931, pp. 145-149.) (11.47/24899 Germany.)

Nine types of joints are shown in sectional sketches. Defects due to electric arc welding are given under three headings:—

(1) Failure of welding material to weld on to the surface.
(2) Failure of successive layers of the weld to weld together.
(3) Formation of blow holes in the weld itself.

Two surface photographs of a long welded joint are reproduced and compared with the X-ray photograph, and types of failure are marked by arrows. A further series of X-ray photographs is reproduced, and the various defects brought out are indicated by arrows or are immediately visible.

Airships

New German Airship, L.2 129, under Construction. (L'Aéronautique, No. 155, April, 1932, p. 125.) (12.1/24900 France.)

Double gasbags are fitted—the outer containing helium and the inner hydrogen. Control by release of hydrogen avoids loss of the relatively expensive helium. This is considered preferable to fitting water recovery plant with increase of weight and head resistance, as in the U.S.A. "Akron."

The following details are supplied:—

	Old Type.	New Type.
Length	235 m.	248 m.
Major axis	33.8 m.	45.5 m.
Minor	30.5 m.	41 m.
Volume	105,000 $m.^3$	200,000 $m.^3$
Fuel and oil	—	60 tonnes
Water ballast	—	6 ,,
Service water	—	4 ,,
50 passengers	—	3 ,,
Freight	—	8 ,,

The frames are 36-sided polygons with 16 m. spacing.

Adiabatic Expansion of Gas in Balloons, etc. (M. Panetti, Aeron. Lab., R. Eng. School, Turin; Atti d. Reale Accad. de Scienze, Vol. 45, 1929.) (12.1/24901 Italy.)

When a dirigible is rising rapidly the expansion of the gas in the cells may approximate to adiabatic expansion. The thermo-dynamic relations are worked out, and it is shown that there is a loss of lift which increases with the rate of ascent.

Indeterminate Stresses in Rigid Airships. (W. Watters Pagon, Aeron. Eng., July-Sept., 1932, pp. 123-139.) (12.2/24902 U.S.A.)

The author discusses the approximations necessarily introduced into complicated frameworks in order to obtain some sort of solution, and makes copious quotations from N.A.C.A. and A.R.C. reports and from classical methods of mathematical theory. Particular cases are illustrated by framework diagrams in which the stresses calculated by the usual methods are entered numerically for different applications of the load. The article is intended to be suggestive rather than exhaustive.

Wireless

Kennelly-Heaviside Layer, Rapid Determination of Virtual Height. (J. P. Schafer and W. M. Goodall, Vol. 20, No. 7, July, 1932, pp. 1131-1148.) (13/24903 U.S.A.)

The displacements of a cathode ray oscillograph tube were used to measure the intensity and time of signals received by reflection from the ionised layers. A definite signal pattern was given out by the sender and the direct and reflected waves were recorded by the oscillograph. The record of the direct wave remained constant in position and amplitude. The reflected wave changed both in amplitude and in displacement from the direct wave according to height of the ionised layers, the length of the path and the absorption. Diagrams of connections are shown and a large number of observations of the height of the ionised layer are recorded. The results are in line with previous work. The rapidity with which observations can be made yields a substantially continuous record.

Absorption of Electrical Condensers. (R. E. W. Maddison, Jrnl. Franklin Inst., Vol. 214, No. 3, Sept., 1932, pp. 327-343.) (13.2/24904 U.S.A.)

The physical significance of various terms entering into the total charging current of the condenser at constant potential is made clear. Elementary mathematical expressions are formed and numerical results of experiments are exhibited graphically. The properties of several insulators are tabulated, as a function of moisture content.

Circuit Relations in Radiating Systems and Applications to Antennæ Problems. (P. S. Carter, Proc. Inst. Rad. Engs., Vol. 20, No. 6, June, 1932, pp. 1004-1041.) (13.3/24905 U.S.A.)

From author's summary.—Expressions for the self and mutual impedances within a radiating system are developed by the use of the generalised reciprocity theorem. These expressions are given in terms of the distributions of the electric field intensities along the radiators.

A method for determining the field intensities is outlined. Formulæ for the self and mutual impedances in several types of directional antennæ are given.

Questions of practical interest in connection with arrays of half-wave dipoles, long parallel wires, and " V " type radiators are discussed. Different types of reflector systems are considered. Curves of the more important relations are shown.

Production of Ultra Short-Wave Oscillations; New Circuit. (H. N. Kozanowski, Proc. Inst. Rad. Engs., Vol. 20, No. 6, June, 1932, pp. 957-968.) (13.3/24906 U.S.A.)

From author's summary.—The circuit consists of two tubes connected by symmetrical plate and filament Lecher systems instead of the usual plate-grid arrangement. The wave length of the oscillations is determined by the length of the plate Lecher circuit. The tuning of the filament Lecher system governs the amplitude of the oscillations.

The radio frequency output is 5 watts.

The Action of Screened Grid Sender Valves. (C. J. de L. de la Sabloniére, H.F. Technik., Vol. 39, No. 6, June, 1932, pp. 191-199.) (13.31/24907 Germany.)

Three types of sender valve of the screened grid type are described and illustrated by photographs and a diagram of connections. The statical characteristics are given and from these the grid and antennæ currents are derived

as functions of the screened grid voltage, which give an insight into the working processes of the valves. The grid and anode losses are considered and the corresponding expressions are formed. Practical conclusions are drawn for the application of such valves and tabulated under eight headings. Relations between antennæ current and grid current are dealt with by modification of the circle diagram of the induction motor. All the quantities discussed are exhibited graphically in seventeen diagrams.

Sheet Metal and Grid Reflectors in Short-Wave Transmission. (W. Köhler, H.F. Tecknik., Vol. 39, No. 6, June, 1932, pp. 207-219.) (13.31/24908 Germany.)

Brief specifications are given of the sender and receiver apparatus and of the layout of the experiments. A photograph shows the installation of a sheet metal parabolic cylindrical reflector for sending 16.8 cm. waves, which was compared with four other shapes and showed much greater sharpness of directional definition. At the receiver end only 42 per cent. of the strength is collected and reflected by the parabolic mirror.

Detection of Two Modulated Waves. (C. B. Aitken, Bell Tele., B.637, 1932.) (13.32/24909 U.S.A.)

From author's abstract.—A discussion of the characteristics of shared channel interference is given and it is shown that there are only two important components of this interference, one being the carrier beat note and the other being what has been designated as side band noise. This latter consists of two frequencies of the undesired station but is shifted upward by a constant amount equal to the difference between the carrier frequencies. The other spectrum is of similar type but is shifted downward by the same amount.

Noises in Receivers. (W. Brintzinger and H. Viehmann, H.F. Technik., Vol. 39, No. 6, June, 1932, pp. 199-207, 282nd D.V.L. Rept.) (13.32/24910 Germany.)

Absolute measurements of noise in short wave receivers would require elaborate apparatus of a nature not yet realised. Mutual comparison of valves for relative intensity of noises is more readily carried out, and three short wave receivers were subjected to comparison of this sort. Measurements made by the D.V.L. are exhibited graphically showing intensity of noise as a function of heating voltage and the anode stream of the grid resistance. The intensity of noise shows a well defined maximum when plotted against heat voltage and grid resistance, but a characteristic rise through the whole range is plotted against anode current. The investigation of the selected receivers is then discussed and the results are shown graphically as functions of the different variables. A number of conclusions are drawn with reference to the design of receiver valves.

Fourteen references are given.

Twin Triode Tubes. (C. F. Stromeyer, Proc. Inst. Rad. Eng., Vol. 20, No. 7, July, 1932, pp. 1149-1162.) (13.5/24911 U.S.A.)

The design of a new valve is described in which two triodes are contained in one tube. Both the positive and negative regions of the grid voltage-plate current characteristic are utilised. A diagram of connections shows the details of the fundamental circuit, the input cathode being directly connected to the output grid. A discussion is given of the characteristics of the circuit, compensation, gain and distortion. The distortion and output are plotted against load impedance and show maximum output at minimum distortion. A quantitative comparison shows twice the output of the pentode and thrice the output of the triode. New solutions of design problems are suggested, by use of twin-triode valves.

The Structure of Cuprous Oxide Rectifiers. (K. Scarf and O. Weinbaum, Phys. Zeit., Vol. 33, No. 8, p. 336.) (13.5/24912 Germany.)

Rectification is due to orientation of Cu_2O and Cu crystals, no bias voltage being required. Cells of this type have successfully replaced the gas-filled photo cell.

The Cathode Ray Oscillograph. (J. B. Johnson, Bell Tele., B.639.) (13.5/24913 U.S.A.)

The elementary theory of the cathode ray tube is given for electrostatic and magnetic deflection. The technical development of the cathode ray tube is summarised and illustrated with 11 sketches and four photographs of different types.

Full details are given of the problems arising in the design and operation of a recent tube.

Twelve oscillograms are reproduced to illustrate applications to high-frequency work.

Radio-Goniometric Deviations on Aeroplanes. (E. Fromy, Pub. Sci. and Tech. du Ministère de l'Air, No. 6, 1932.) (13.6/24914 France.)

The metallic parts of an aeroplane structure form closed circuits of a complex geometrical nature. Reference is made to the work of R. Mesny, which is carried further in the present paper. Induced currents in closed circuits are first discussed in a general manner on the single assumption that the disturbing field is uniform in the interior of the circuit. A general formula is obtained containing Mesny's formula in a particular case. Experimental verifications were carried out taking into account the various sources of error inherent in radio-goniometry. Numerical examples are given from experience on particular aeroplanes. Methods of compensating the errors are discussed.

New Wireless Apparatus in German Aerial Transport. (F. Eisner, Z.F.M., Vol. 23, No. 9, 14/5/32, pp. 259-266, 275th D.V.L. Rept.) (13.6/24915 Germany.)

A description is given of the standard wireless apparatus evolved for air navigation through the joint efforts of the industry, the Luft Hansa, the Central Insurance Company, and the D.V.L. Two photographs of the installation in an aeroplane are given. Weights of component parts are tabulated, and sketches show some of the details, the scheme of connections, and the general arrangement in an aeroplane. Some experimental wireless measurements are also reproduced and include two oscillograms, eight graphical charts of the electrical characteristics and the corresponding numerical tables.

Reference is made only to the 1932 German handbook, "Applications of wireless in air navigation."

Photo-Electric Cell Recording Device. (Z.V.D.I., Vol. 76, No. 35, 27/8/32, p. 838.) (13.7/24916 Germany.)

A new Siemens apparatus has a rotating sector which renders intermittent a beam of ultra-red rays falling on a photo-electric cell and produces an alternating current. The current is rectified and holds open a relay circuit. Interruption of the beam is recorded by the closing of the relay. A number of reflections by mirrors may be interposed between source of light and cell, giving great flexibility in selecting the path of the beam.

Modes of Vibration of Quartz Plates by Interferometer. (W. D. Dye, Proc. Roy. Soc., Vol. 138, No. A.834, 1/10/32, pp. 1-16.) (13.81/24917 Great Britain.)

The mode of vibration of quartz crystal rods and plates is of importance in constructing frequency controls in radio transmission.

The behaviour of rods has been worked out with sufficient completeness, both experimentally and mathematically. In the present paper the modes of vibration of quartz plates are studied by methods of optical interference.

Flexural, torsional and compression vibrations offer a great variety of possible modes.

Numerous typical cases are recorded by direct photography and by stroboscopic methods.

Application of Quartz Plates to Radio Transmitters. (O. M. Hovgaard, Bell Tele., B.673.) (13.81/24918 U.S.A.)

Temperature variations are the chief source of frequency variations and a necessarily somewhat elaborate thermostatic control is described as developed in the laboratory.

Two units specially designed for aircraft work are described and illustrated by photographs of parts, one weighing 5 ozs., the other less than 1 lb.

Two graphical records show a frequency control within 0.01 per cent. over a range of external air temperatures from $-40°$, to $+40°$, the frequency being 3,926 kilocycles per second.

Craft Location

Recording Balloon Theodolite. (Z.F.M., Vol. 23, No. 15, 12/8/32, p. 471.) (15.10/24919 Germany.)

A photograph shows the main features of the instrument. The two eyepieces are arranged at right angles to the axis of the telescope. Altitude and azimuth appear in the field of the main telescope and can be read off, and recorded on a polar diagram by pricking with needle styluses.

(Abstractor's Note.—A similar instrument was embodied in a recording theodolite to the design of the Naval Air Service in 1917.)

Noise

Sounds Emitted by Rotating Airscrews. (J. Obata and others, Aer. Res. Inst. (Tokyo) Rept., No. 80, July, 1932.) (15.34/24920 Japan.)

The sounds emitted by six model airscrews, one-third and one-fourth full size, were recorded by condenser microphone, amplifier and oscillograph. The records supply an harmonic analysis of the sound into fundamental tones and overtones, and the amplitudes should be a measure of the intensities. Numerous oscillograms are reproduced and graphical representations are given of the relative intensities of the components.

Sound Emitted by Airscrews. (C. F. B. Kemp, Proc. Phys. Soc. 44, pp. 151-162.) (15.34/24921 Great Britain.)

The first six harmonics of the sound produced by an airscrew at a fixed point were investigated, the total sound energy being 18 watts, of which 9 watts were due to the fundamental note and 7 watts to the second and third harmonics together. Beyond 200 feet from the hub the intensity is inversely as the square of the distance. Within this distance directional effects confuse the observations. Maximum intensity was observed at 15° to 30° behind the airscrew disc.

Cathode ray oscillograms indicate significant frequencies up to 600.

Lynam and Webb's work is discussed.

D.V.L. Research Work—Noise Measurement. (Luftwacht, No. 8, August, 1932, p. 320.) (15.38/24922 Germany.)

A new instrument for analysing the gamut has been designed in application of the methods of Barkhausen and Grutzmacher. The partials range in frequency from 100 to 1,000 Hertz and the quality of the noise is similar for different types of aircraft. The cabin walls damp the higher frequencies more than the lower. The results have been applied to the design of an echo sounding apparatus with a sending note of frequency 3,000 Hertz, and with sound filters between receiving and recording apparatus.

Aircraft, Unorthodox

Experimental Characteristics of an Aeroplane with a Hollow Cylindrical Body. (L. Stipa, Riv. Aeron., No. 7, July, 1932, pp. 75-86.) (17.03/24923 Italy.)

The body is substantially a hollow cylinder acting as a guide channel for the airscrew jet. The pilot's cockpit is built into the thickness of the upper surface. Three diagrammatic sketches in plan and front and side elevation show the external diameter of the body as 488 mm., the internal diameter as 400 mm., and airscrew diameter as 320 mm. The span, measured to scale, appears to be 2.9 m. It is stated that the model was tested in the aeronautical research tunnel, and graphical characteristics are reproduced. It is claimed that the airscrew efficiency is increased by the guide channel.

A general specification of a full-sized machine is given.

Stipa Aeroplane. (Flight, Vol. 24, No. 43, 20/10/32, p. 995.) (17.03/24924 Great Britain.)

Three photographs of an experimental aeroplane are reproduced and the following figures are quoted:—

Span	13.3 m.
Wing area	19 m.^{2}
Tare weight	600 kg.
Gross weight	800 kg.

See previous Abstract.

Military Value of Autogiro. (H. L. Lewis II (? sic), U.S. Air Services, Vol. 17, No. 10, Oct., 1932, pp. 36-37.) (17.05/24925 U.S.A.)

A highly optimistic forecast is given of possible uses of the autogiro for special services in war.

The Rotating Wing Flying Machine. (M. Schrenk, Z.V.D.I., Vol. 76, No. 35, 27/8/32, pp. 843-846.) (17.05/24926 Germany.)

The modern form of autogiro with gear drive to rotating wing for starting purposes is described. From the performance figures supplied by the Autogiro Co. the three-blade lifting screw is a distinct improvement on the four-blade gyro plane. The omission of the lower stabilising plane is anticipated. It is considered that the autogiro is only suited for reliable short flights.

Propulsion by Reaction. (M. Roy, Pub. Sci. et Tech. du Ministère de l'Air, No. 1, 1930.) (17.2/24927 France.)

Part I discusses reaction-propulsion by rockets and by fuel burning with a forced supply of air and exhausting through a shaped nozzle.

Part II deals with airscrews, the blades of which are driven by the reaction of gas exhausting from nozzles at the blade tips along the negative axis of motion relative to the air. It is useful to have the theoretical relations worked out and tabulated systematically, but the region of applicability remains above

speeds which can be considered feasible in the present state of development, *i.e.*, above 500 m.p.h.

Students of the possibilities of reaction propulsion should avail themselves of the results worked out in this paper.

Motorless Flight. (Bulletin No. 3 of the International Commission for the Study of Motorless Flight, June, 1932.) (17.4/24928 Germany.)

The bulletin contains a review of gliding activities in various countries during the past year. Germany appears to be the only country with a proper organisation, and there the sport has maintained its position. Recent developments include starting by motor car and towed flights. The German Gliding Association favours the construction of gliders designed as such but fitted with auxiliary engines, to familiarise pupils with the piloting of power aeroplanes at low cost and risk.

Aircraft Carriers

Navies and the Aeroplane. (F. H. Wagner, Army Ord., No. 73, July-Aug., 1932, pp. 29-35.) (18.01/24929 U.S.A.)

The author develops the usual argument with reference to battleships *versus* aeroplanes, and appears to favour the latter. He considers the possibilities of dirigibles to be small. The use of poison gases against ships is put forward as a major problem of defence for the latter. Reference is made to chloro-vinyl-dichloro-arsine, which is stated to cause death by wetting a skin area of a few $cm.^2$

An air photograph of the U.S.S. " Lexington " is reproduced.

Physiological Conditions

Human Sensibility to Shocks. (Reiher and Meister, Forschung, Vol. 3, No. 4, July-Aug., 1932, pp. 177-180.) (19.29/24930 Germany.)

Graphical records are reproduced of typical shocks occurring in engineering practice, and of shocks produced by the apparatus employed in the investigation. Six degrees of intensity are selected:—

0.—Imperceptible.
1*a*.—Just perceptible.
1*b*.—Easily perceptible.
1*c*.—Strongly perceptible, but endurable.
2*a*.—Unpleasant, dangerous if continued.
2*b*.—Extremely unpleasant, immediately harmful.

Three diagrams are constructed with the duration as abscissa and amplitude of the shock as co-ordinate.

The regions corresponding to the above classification appear as parallel straight lines inclined at from 20° to 45° with the horizontal axis. These lines are displaced vertically downward as the number of shocks increases.

Another type of diagram has the number of shocks per second as the axis of abscissæ, and in this case the regions are bounded by straight lines inclined at small negative angles to the horizontal axis. A table gives comparison between the effects of horizontal shocks and of pure harmonic horizontal oscillation applied to a man standing upright.

These results enable an immediate estimate to be made as to whether shocks or vibrations of known intensity and duration are likely to be dangerous.

The Semi-Circular Canal of the Ear as a Direction Indicator. (E. Everling, Z.F.M., Vol. 23, No. 12, 24/6/32, pp. 342-343.) (19.29/24931 Germany.)

In blind flying, without instruments and without visual fixed points of reference, it is a common experience that the pilot loses all sense of altitude and direction. The author states that, on moving the head from side to side, the increase of acceleration when turning the head with the aeroplane and the decrease on turning the head against the aeroplane produces a difference of physiological sensations so clearly accentuated that the direction and approximate rate of the turn can be estimated. Training can be carried out to some extent in rotating chairs of cabins mounted on the ground, and the required perceptions developed.

References are given in nine footnotes.

Equipment

Collapsible Boat for Seaplanes. (Sci. Am., Vol. 147, No. 4, Oct., 1932, p. 236.) (20.34/24932 U.S.A.)

Two illustrations show the boat or raft inflated, with two passengers, and deflated. Two concentric tubes, independently inflatable, reduce the danger of collapse by puncturing. It is stated that the design is under the supervision of the U.S. Army Air Corps.

Lighting

Aeroplane Lights and Landing Ground Illuminations. (B. Duschnitz, Licht und Lampe, No. 12, 9/6/32, pp. 179-181; No. 13, 23/6/32, pp. 196-198; No. 14, 7/7/32, pp. 214-215.) (21.09/24933 Germany.)

In Part I a description is given of aeroplane lights with fixed or movable reflectors, streamlined for external mounting, or without fairing when sunk in the structure. Five photographs are reproduced.

Descriptions of ground lights on fixed and movable standards or retractable below the surface are also illustrated by two photographs. In Part II, systems of ground lighting are considered. Three travelling searchlights, a fixed 24 k.w. standard and a battery of eight 3 k.w. standard lights are shown in photographs. A typical lighted area is shown in diagram with a boundary curve of equal lighting intensity. A diagram of intensity for the 3 k.w. standard light is also shown.

In Part III, two systems of wiring are shown in diagram, one with all lights on a common main, the other with independent wiring to each group of lights.

Recommendations of International Airways Lighting Commission. (F. Born, Z.F.M., Vol. 23, No. 12, 24/6/32, pp. 343-346.) (21.095/24934 Germany.)

Diagrams show typical lighting of an aerodrome and of an air route. The general activities of the Commission are summarised under fourteen headings.

Visual Range of Lights at Night. (Bennett, Quarterly Journal of the Met. Society, Vol. 58, No. 245, July, 1932.) (21.09/24935 Great Britain.)

Author's summary.—The visual range of a point source of light is given by the formula:—

$$\frac{\text{Intensity} \times \text{transmission}}{(\text{Distance})^2} = \text{constant}.$$

Experiments are described in which the dependence of the constant on the brightness, B, of the background, is found to follow roughly the empirical formula, constant $= 0.12 + 10^{-4} B^{2/3}$ where the constant is in c.p./km.^{2}, and the background brightness is apparent c.p./km.^{2}.

From these results, and their application to some observations quoted by Bigg, deductions are made as to the magnitude of the effect of background brightness on the visual range of lights, and on the relation between the visual range of lights at night and of ordinary objects by day.

Meteorology

The Electrical Properties of Dust and Fog. (H. Sachsse, Ann. d. Phys., Vol. 14, No. 4, Aug., 1932, pp. 396-397.) (21.22/24936 Germany.)

Experiments were carried out on a variety of substances by the Millikan condenser method. Individual fog particles produced either by condensation of gases or the so-called " atomisation " of a liquid by a jet of compressed air are not electrically charged. This applies to paraffin oil. Fogs containing products of combustion are highly charged.

Friction plays an important part in the electrification of clouds and accounts for the well-known electrical properties of sand and snow storms.

Eight references are given.

Aerodynamics and Hydrodynamics

Velocity Field Round a Surface of Revolution with a Symmetrical Joukowski Profile as Meridian Section. (C. Ferrari, Aeron. Lab., R. Eng. School, Turin, R. Academia d. Sci. d. Torino, Series 2, Vol. 47.) (22.1/24937 Italy.)

A mathematical analysis is worked out in extension of Joukowski's methods to three dimensions. Some numerical results are given.

Conformal Transformation of Two Circles into Two Wing Profiles. (C. Ferrari, Aeron. Lab., R. Eng. School, Turin, R. Accad. d. Sci. d. Torino, Series 2, Vol. 67, 1930 and 1931.) (22.1/24938 Italy.)

The problem is stated in two steps; first the determination of the potential in the region external to the circles; secondly, the determination of the transformation from the circles to two wing profiles. The circles are first transformed into segments of straight lines, the transformation necessarily involving elliptic functions. Further transformations by methods analogous to Joukowski's transform the straight lines into segments of circles and into profiles of the Joukowski type.

A graphical procedure is given and the results are compared with calculated points, for which a numerical table is given, and agree as closely as is possible on a drawing board.

Aerodynamical characteristics of a biplane with determinate wing profiles and a number of geometrical properties connected with the transformation are worked out in a manner analogous to the work of V. Mises on a single Joukowski profile.

Mutual Effects of Eddy Systems. (A. Betz, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 164-174.) (22.1/24939 Germany.)

It is to be noted that the problems dealt with are substantially two-dimensional on the lines of Lamb's " Hydrodynamics," 5th Edition, para. 154. It is shown that the centre of intensity remains fixed while the moment of intensity formed in a manner analogous to the moment of inertia of distribution of mass also remains constant.

An application is made to the rolling up of the vortex sheet trailing from a wing. The sheet is assumed to roll up into two substantially circular tubes of vorticity.

The basis of the treatment appears to lie in the radial distribution of vorticity assumed in equation 20, for which no experimental or mathematical physical reason is offered. Subject to this assumption the numerical relations are worked out and shown graphically.

The effect of trailing vortices behind a system of lifting surfaces arranged as in a Venetian blind is also dealt with, and some elementary results are obtained subject to the usual simplifying assumptions.

The presentation of these elementary results in an explicit form should help to make clear the underlying ideas.

Eleven references are given.

The Eddy System in a Plane Turbulent Flow. (F. Magyar, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 157-163.) (22.1/24940 Germany.)

The flow is considered as compounded of a mean steady motion on which is superposed a variable motion due to a distribution of vorticity.

The distribution of vorticity is uniform along tubes at right angles to the flow, thus maintaining the two-dimensional nature of the problem. Further, the vorticity is assumed to be a periodic function of time and position—expressible in a Fourier series. The typical periodic term is formed and the velocities are obtained by integration over the field and over a half period. The effect of the vorticity on the mean velocity profile is shown graphically for a particular assumption. Suggestions are made for applying the method to observed conditions.

Abstractor's Note.—As experiment indicates the breakdown of two-dimensional conditions, it is not clear to what extent the two-dimensional treatment will offer useful results.

Wake of Two-Dimensional Wind Flow. (H. Schlichting, Ing. Archiv., Vol. 1, No. 5, Dec., 1930, pp. 533-571.) (22.1/24941 Germany.)

The author attacks the solution of the differential equations of turbulent viscous fluid motion along the lines suggested by Prandtl on the assumption that the effects of distributed eddies may be averaged in time and space and produce shear forces analogous to ordinary viscous motion. The so-called inertia terms are introduced by successive approximations of which the first and second are developed fully, further approximations leading to intractable computations.

The order of magnitude of various terms is classified with a view to selecting suitable approximations, but the assumptions appear, in part at least, to be drawn from the form of wake in steady flow under viscous shear forces. The first approximate solution is an algebraic equation of the sixth degree, which has to be fitted to the boundary conditions observed or assumed from the analogy of steady viscous flow. This is readily done with the seven arbitrary coefficients at disposal. The second approximations are obtained in the form of additive terms for the velocity components, by the superposition of which more elaborate curves are built up. A fit is obtained for the wake behind two parallel cylinders side by side.

Abstractor's Note.—A series of successive diagrams representing the flow at consecutive time intervals and exhibiting the transference of fluid, momentum, and heat is required to give some sort of definiteness to the analogy between the mean free path of kinetic theory and the mean transference path of the suggested analogy with turbulent motion. In the absence of such a physical basis the paper leaves an impression of an elaborate fitting of equations to known or assumed curves, the nature of the operation being obscured by a mass of analysis.

Examples of Irrotational Flow in Three Dimensions. (A. Alayrac, Pub. Sci. et Tech. du Ministère de l'Air, No. 13, 1932.) (22.1/24943 France.)

Elliptic and ellipsoidal co-ordinates are applied to two-dimensional and three-dimensional flow about elliptic cylinders and ellipsoids, hyperboloids, etc. An attempt to account for resistance by cyclic motions in three dimensions does not appear to lead to any definite results.

Measurements of Velocity and Pressure in Three-Dimensional Flow. (F. Krisam, Z.F.M., Vol. 23, No. 13, 14/7/32, pp. 369-373. Rept. from Inst. of Hydraulic Machines, Tech. High School, Karlsruhe.) (22.1/24944 Germany.)

A description is given of a spherical pressure head with five perforations connected to manometers and calibrated for measurement of velocities in terms of pressures, the mean direction of flow being also determined approximately.

The pressures agree fairly closely with the values calculated from hydrodynamical theory up to an angle of 60° from the forward head water branching point, and thereafter fall off rapidly in the region where the flow is diverted from the surface of the sphere.

A number of calibration curves are given and comparisons are made with numerical results obtained by other experimenters. The apparatus is applied to measure velocities in the Kaplan turbine and the results are given graphically.

Thirty references are given.

Calculations of Two-Dimensional Periodic Flow in the Boundary Layer. (H. Schlichting, Phys. Zeit., No. 8, 15/4/32, pp. 327-335.) (22.1/24945 Germany.)

A definition is given of a new type of boundary layer flow which partly meets the serious objections recently raised by visual observation with the ultra-microscope (see Abstract No. 24/24123). For two-dimensional flow along a plane boundary the surface of an ideal boundary layer is assumed to be a wave surface with fixed nodes equally spaced along a parallel plane, but with an amplitude which is a periodic function of the time. Admitting that such a surface exists, the flow in a boundary layer also becomes a periodic function of time. A diagrammatic representation of the resulting longitudinal waves near the boundary recalls G. I. Taylor's note to the abstracted paper mentioned above.

It is possible that in actual motion the nodes are not stationary. The idea, however, appears to be valuable, and might be generalised by introducing moving nodes. In the present paper application is made not to steady flow affected by turbulence but to periodic flow set up by an oscillating cylinder.

The equations of motion are written down and first and second approximations are worked out on lines similar to the author's previous paper. The results are shown graphically and compared with Andrade's photographs of Kundt dust figures (see Abstract No. 23/23116). Generally the resemblance is striking, and it may be inferred that the mathematical physical treatment is a satisfactory approximation.

Hollow Spindle-Shaped Liquid Jet. (K. Ito, Aer. Res. Inst. (Tokyo), Rept. No. 81, July, 1932.) (22.1/24946 Japan.)

Experiments were carried out on a hollow jet of water with air at a pressure of several millibars applied at the axis. Numerous photographs of the hollow jets thus obtained are reproduced.

The object of the experiments is not quite clear.

Configuration of Streamlines shown by Formation of Rust. (F. Numachi, Phil. Mag., Vol. 14, No. 91, Sept., 1932, pp. 496-500.) (22.1/24947 Great Britain.)

The radial flow of water past guide vanes gave a formation of rust on the iron end plate which indicated the direction of the streamlines along the boundary. Three photographs are reproduced which show clearly the lines thus formed. The discontinuity of flow at the tip of the guide vanes is well defined.

Flow of Water through a Circular Pipe; Effect of an Axial Wire. (A. Fage and H. C. H. Townend, Phil. Mag., Vol. 14, No. 91, Sept., 1932, pp. 500-508.) (22.2/24948 Great Britain.)

The investigations of Lea and Tadros on the effect of an axial wire on the flow of water through a circular pipe are discussed. The experiment was repeated and the motions observed by ultra-microscope. A number of discrepancies arose and these are discussed carefully. At low Reynolds numbers the motion is found to be steady. Slight irregularities in mounting may account for the discrepancies.

Motion of Water in a Tube. (J. Baurand, Ann. d. Phys., Vol. 18, Sept., 1932, pp. 107-194.) (22.2/24949 France.)

Waves were produced at the surface of a basin 1.12 metres in diameter and observed optically. Methods and results are described in minutest detail. Wave velocities and amplitudes are given graphically and in tables and some photographs of wave trains are reproduced.

Analysis of Mutual Influence of Aeroplane Organs. (Abridged Report of Paper by C. Weiselsberger read at 21st meeting of W.G.L., 1932. Z.F.M., Vol. 23, No. 18, 28/9/32, pp. 533-535.) (22.4/24950 Germany.)

Interfering organs are considered in three principal pairs: Airscrew-Body, Body-Wings, Wings-Airscrew. The influence of the body on the air stream, in which a tractor airscrew works, is shown diagrammatically and a simple formula expressing the effect of a simple source near the nose of the body represents closely enough the actual effect.

The influence of body on wing lift is considered in terms of distribution of circulation along the span. This is expressed in a Fourier series in which enough terms can always be taken to give as close a fit as is desired. Numerical data and results for two nacelles built into a wing are given graphically and show a satisfactory fit between observed and calculated lifts with eight terms of the Fourier series.

The mutual influence of airscrew and wings is discussed, superposing velocity fields in accordance with previous investigations to which reference is made. Lift-drag curves are calculated for two cases—the airscrew set above the wing and below the wing, and a close fit with experimental points is obtained.

The Eddy System in Turbulent Flow between Planes. (F. Magyar, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 157-163.) (22.4/24951 Germany.)

The mean flow is taken as parallel to a given direction. The conceptions of Prandtl and others are stated, and an attempt is made to build up expressions representing the eddy systems and giving a flow approximately equivalent to the actual stream. Developments in Fourier series are assumed for the periodic function representing the eddy motion, and the resulting expressions are integrated

over the whole region of vorticity to give the resulting superposed motions at any point. The expressions are so general that no contradiction of the facts need be anticipated. On the other hand, mere qualitative agreement does not appreciably advance the solution of the general problem.

Twenty-one references are given.

Air Resistance of Spheres at Medium and High Speeds. (C. Pasqualini, Aeron. Lab., R. School of Engineering, Turin; IVth Congress, Internat. Rept., Vol. 4.) (22.4/24952 Italy.)

Experiments were carried out on the resistance of spheres at velocities up to 300 m. per sec., on a whirling arm. The distribution of pressure is plotted for four values from 57 m. per sec. to 180 m. per sec. Measurements were also carried out on a sphere rotating in a uniform current. The results are tabulated.

Air Resistance of Spheres at the Velocity of Sound. (Riv. Aeron., No. 3, March, 1931.) (22.4/24952 Italy.)

Spheres mounted on a whirling arm were carried at velocities up to 340 m. per sec. Observed distributions of pressures are plotted graphically.

Resistance of Projectiles at Oblique Angles at Speeds Less than that of Sound. (F. Burzio, Aeron. Lab., R. Eng. School, Turin, Riv. D'Artiglieria e Genio, June, 1929.) (22.4/24953 Italy.)

A summary is given of measurements of pressures on a projectile, obtained at the Royal School of Engineering, Turin, at velocities up to 240 m. per sec. Rough curves of pressure distribution are drawn for velocities of 60, 150 and 240 m. per sec., and the pressures are integrated over the surface in order to obtain the total force and moments on the projectile. The distribution of pressure along the axis is shown graphically. The conclusion is reached that the lateral force is two to three times the resistance for an angle of 11°.

Experimental Determination of Fields of Velocity in Two and Three Dimensions by the Electrical Analogy. (C. Ferrari, Aeron. Lab., R. Eng. School, Turin, L'Aerotecnica, Vol. 10, No. 6, June, 1930.) (22.4/24954 Italy.)

The mounting of the body in the tank and the methods of recording equal potential lines are described. Worked-out results are shown for a wing profile and for a dirigible.

In a reprint of Riv. d'Artiglieria e Genio, June 1930 (F. Burzio), the ideal field of flow round a projectile is worked out. Tests were carried out by the same author on the resistance of projectiles at the velocity of sound and the results are given graphically and in tables in a reprint from Riv. d'Artiglieria e Genio, Sept./Oct. 1931.

Two Problems in Potential Theory. (T. C. Fry, Bell Tele., B.671.) (22.4/24955 U.S.A.)

The potential field due to a circular cylinder surrounded by a coaxial circular cylinder slotted between two generators is worked out by the methods of conformal transformation. The field due to two parallel planes, one with a circular slot, is also worked out in elliptic co-ordinates.

The results have applications to the production of beams of electrons by shielding the source with slotted metal sheets.

Long Distance Gas Transmission (Hamm-Hanover). (Z.V.D.I., Vol. 76, No. 38, 7/9/32, p. 916.) (22.5/24956 Germany.)

Power gas is transmitted 60 miles through a 50 cm. diameter pipe line under a pressure of one atmosphere. The resistance coefficients at different Reynolds numbers are in satisfactory agreement with the results of Jakob and Erk (Forschung Arb. Ing. Wes. No. 267).

Materials, Elasticity

The Factor of Safety of a Statically Indeterminate Framework. (E. Melan, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 129-136.) (23/24957 Germany.)

The author discusses the relation between the factor of safety and the cross-sectional area of individual members. The course of the deformation is considered up to and beyond yield point of a particular member. The inclusion of a redundant member which is strained beyond its yield point may reduce the factor of safety of the frame as a whole.

Static Deflection of a Clamped Rectangular Plate. (H. Schmidt, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 142-151.) (23/24958 Germany.)

The usual partial differential equation of the fourth order in two variables is considered. A solution is written down in the form of an integral, the integral containing products of Bessel functions and elementary functions.

The boundary conditions are introduced. A valuation of the integrals and series is discussed and formal solutions are obtained. The analysis is heavy and unsuitable for abstraction.

Deformation of a Rectangular Plate with Rigidly Held Edges. (H. Schmidt, Z.A.M.M., Vol. 12, No. 3, June, 1932, p. 142-151.) (23/24959 Germany.)

The solution proceeds along formal lines, and expressions are obtained for the flexion of the plate under specified loads.

The author gives three references to his own previous work.

Determination of the Position of Equilibrium from Observation of Damped Oscillations by the Theory of Probabilities. (M. Schuler, Z.A.M.M., Vol. 12, No. 3, June, 1932, pp. 152-156.) (23/24960 Germany.)

It is pointed out that the usual method of determining the mean position is inaccurate. A more precise result is obtained by applying the method of least squares.

Three references are given.

Elastic Limit of Metals under Tri-Axial Stress. (G. Cook, Proc. Roy. Soc., A.833, Sept., 1932, pp. 559-574.) (23.2/24961 Great Britain.)

A relation between the principal stresses at the elastic limit is sought. No satisfactory correlation of the test results with current hypothesis, *e.g.*, maximum shear stress constant, maximum shear strain energy constant, maximum total strain energy constant, is obtained.

The exposition is obscured by a variety of units, mms., cms., inches, lbs., tons and atmospheres.

Recovery of Elasticity in Overstrained Steel. (S. L. Smith and J. V. Howard, Proc. Roy. Soc., Vol. 137, A.833, Sept., 1932, pp. 519-530.) (23.2/24962 Great Britain.)

Elasticity is defined as proportional or linear when the stress strain diagram is a double straight line and as non-linear when there is a definite hysteresis loop which is repeated over a number of stress cycles. A period of repose after overstrain may restore the linear elasticity. Overstrain may merely shift the linear stress strain diagram by reason of permanent strain, but beyond a certain overload hysteresis loops appear with increasing areas. A table gives a specification of fifty test pieces with a summary of results in recovery of elasticity.

REVIEWS

The Air Annual of the British Empire, 1932-33

Gale and Polden. 21/- net.

This is the fourth year of the "Air Annual of the British Empire," under the able editorship of Squadron Leader C. G. Burge. The Air Annual has taken a very definite place among the increasing works of reference on aviation, and its summaries, statistics and authoritative articles on Empire aviation are invaluable.

In the volume under review there are articles on Flying Club Progress, by Major C. C. Turner, A.F.R.Ae.S.; the Growth of Gliding and Soaring Flight, by C. H. Latimer-Needham, F.R.Ae.S.; Requirements for Civil Aerodrome Design, by John Dower, M.A., A.R.I.B.A.; Insurance, by Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E.; Military Aircraft, by Major Oliver Stewart, M.C., A.F.C.; Light Aircraft, by Major C. C. Turner, A.F.R.Ae.S.; Seaplane Development, by Major R. E. Penny, O.B.E., A.F.R.Ae.S.; the Progress of British Aero Engines, by Major G. P. Bulman, O.B.E., A.F.R.Ae.S.; the British Aircraft Industry in 1931-32, by Sir John Siddeley, C.B.E., F.R.Ae.S.; and Performance of Aircraft, by H. A. Meitam, A.F.R.Ae.S.

The above list of articles alone indicates the authority of the new edition of the Air Annual. It is supplemented by a series of articles, tables and summaries covering every side of aviation progress in the Empire. These are volumes to buy yearly and to keep.

Blind Flight in Theory and Practice

W. C. Ocker and C. J. Crane. 3$ nett. Naylor Printing Co.

This book is a treatise on blind flying as it is practised in America, and contains an account of the reactions of normal flying on the human organism, an extension of this account to the peculiar conditions of blind flying. Starting from this basis, the authors give a description of the numerous instruments that have been developed in America for use in blind flight, stating their qualities and defects and pointing out how they assist the blind flying pilot in his task. Direction-finding instruments of all types are also described.

There is also a full description of blind flying training, fog landing systems, leader cable methods and other relevant matters, but there is no reference to blind flying methods developed in Europe or elsewhere, the book being confined entirely to American practise.

Now that the aeroplane has reached a point when its commercial use as an instrument of transport is rapidly developing, it is essential that means of flight through fog be provided so that the regularity of a transport service may be assured. Now such flight may be safely carried out by an experienced pilot provided with the necessary instrument equipment, provided always that he can alight on an aerodrome sufficiently clear from fog to enable him to see to land.

But this can only be done by adding to the mechanical equipment of the machine such apparatus as instruments fitted with gyroscopes running at 25,000 revolutions per minute, hair springs and delicate control mechanisms. The breakdown of one such instrument may be the cause of the pilot losing control which may involve the death of the occupants and the loss of the machine. They are even more important than the power plant, because in the usual three-engined transport machine, flight is possible with one engine stopped.

If blind flying is to be normally resorted to as a matter of airway routine it is to the reliability of the instruments that attention should be directed, and it should be said that the details of many of those described in this book do not inspire one with great confidence. Duplicates may, of course, be carried, but the difficulty of arranging for duplicate instruments in the already overcrowded cockpit of a transport aeroplane is serious.

It is probable that the final solution of this problem, as far as transport is concerned, will be the providing of some form of automatic pilot. This, again, is an intricate piece of apparatus; failures are not unheard of and, if it is to come into general use, reliability must be nearly absolute.

The authors of this work are to be congratulated on producing a very useful manual. It should be read by all those interested in blind flying, or, indeed, by all those interested in aircraft design or operation.

HOW INSECTS FLY*

BY

R. E. SNODGRASS

Bureau of Entomology, United States Department of Agriculture

A particular interest attaches to the study of the wings of insects, because, in some respects, they act more after the manner of human inventions for aerial locomotion than do the wings of any other flying creature. Though man has never been successful in equipping himself with wings, and has largely given up the hope of acquiring them, he has succeeded in making machines that will fly; and, whether his craft is lighter than air or heavier than air, its driving mechanism is a set of rotating blades, the nearest counterparts of which in the animal world are the rapidly-whirring wings of certain insects.

The wings of insects are organs *sui generis*, which is to say, there is nothing else exactly like them. In fact, it may be claimed that insects are the only animals that possess true wings. The wings of a bird, or the wings of a bat, are merely the forelegs of the animal made over for purposes of flying; the flying fishes glide through the air on their pectoral fins, but these organs also are the fore limbs, which were modified primarily for swimming; the flying mammals are equipped with folds of skin along the sides of the body, which enable them to extend their leaps from one tree to another, but such dermal expansions are parachutes rather than organs of true flight.

I. The Origin of Insect Wings

Insects are among the oldest of all animals that have living representatives on the earth to-day.

The conditions of the Carboniferous swamp forests were favourable to two classes of insects, namely, insects adapted to living in the forests themselves, and others adapted to unhindered flight over open stretches of water. A review of the known Carboniferous insects shows that these two types actually predominated, or almost exclusively made up the insect fauna of the forests and swamps of that time. The insects of the first class consisted principally of roaches (Fig. 1); those of the second class comprise dragon flies, May-fly-like insects, and insects of an extinct group known as the Paleodictyoptera (Fig. 2 A). It is very doubtful, however, that the insects known from the Carboniferous rocks represent anything like the variety of insect forms that existed at the time these rocks were laid down, for there were large areas of open country on both continents where many species may have flourished whose remains have not been preserved.

The remarkable thing about the Carboniferous insects is not that they existed in great abundance at so remote a period, but that they differed comparatively little from modern insects. Of course, entomologists find many characters that separate the Paleodictyoptera and their associates from their modern relatives, but the distinctive features have to do mostly with details of the wing venation. All the Carboniferous insects so far discovered had two pairs of well-developed wings, the structure of which is so nearly like that of the

* Abridged. Reprinted by courtesy of the Smithsonian Institution.

wings of present-day insects that only a specialist would discover the differences. In bodily form and structure there was nothing to distinguish a Carboniferous insect from one of its modern descendants; the oldest species known had a head, a thorax, and an abdomen, with four wings and six legs carried by the thorax.

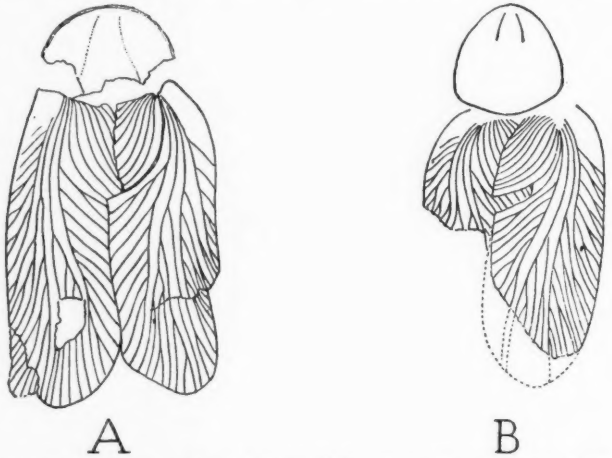

FIG. 1.—Carboniferous roaches. A, *Asemoblatta mazona* (from Handlirsch after Scudder); B, *Phylloblatta carbonaria* (from Handlirsch).

One important conclusion, therefore, that we must draw from a study of the Carboniferous insects is that they do not by any means represent the primitive ancestors of insects. Having already fully-developed wings, the Carboniferous insects themselves must have been evolved during millions of years preceding their time from wingless forms of which we have no record. Any attempt to

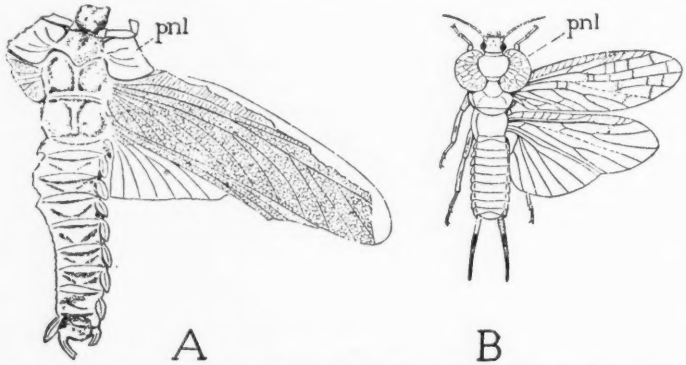

FIG. 2.—Paleozoic insects with paranotal lobes (*pnl*) on the prothorax. A, *Stenodictya lobata*, one of the Paleodictyoptera (from Brongniart); B, *Lemmatophora typica*, a primitive stone fly (from Tillyard).

explain the genesis of insect wings, then, must be purely conjectural, but we may arrive at a fairly satisfactory conclusion concerning their origin by a study of the wings themselves and the thoracic segments that support them. In one feature, however, some of the ancient insects do give us a slight clue to the possible nature of the primitive wings, as we shall see presently.

Among the Carboniferous insects there are frequently found species which have a pair of small, flat lobes resembling the developing wing pads, which extend laterally from the margins of the *first* segments of the thorax, or prothorax. (Fig. 2 A, B, *pnl.*) These prothoracic lobes suggest, therefore, that the wings have been evolved from similar lobes on the mesothorax and metathorax. There is no evidence to suggest the improbable view that insects ever had three pairs of fully-developed wings used for flight; but we may assume that three pairs of flaps, or paranotal lobes as they have been termed, forming a series of overlapping plates on each side of the thorax (Fig. 3), could have served some important function. The idea that comes most easily to the imagination is that

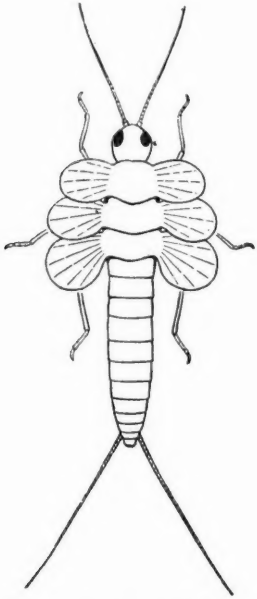

FIG. 3.—A suggestion of the possible structure of a primitive insect provided with three pairs of glider lobes, or lateral extensions of the back plates of the thoracic segments.

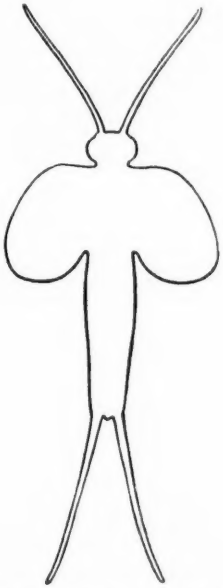

FIG. 4.—Outline of a model that can be made, when properly ballasted, to show something of the possibilities of a glider insect.

the fanlike extensions of the body wall constituted a glider apparatus, enabling its possessor to sail downward from elevated positions, or perhaps from one elevation to another, as do the modern flying squirrels with their parachute-like folds of skin stretched between the legs on the sides of the body.

Something of the possibilities of a sailing or gliding insect may be demonstrated with a model cut from a piece of thin cardboard according to the pattern of Fig. 4, and given a proper ballast by attaching a weight beneath. When passively released from any altitude the cardboard model drops straight down; when given a forward impulse, however, it can be made to sail downward with a graceful forward glide extending a distance varying with the height from which it is projected. The ballast is most important; it may be a crumpled piece of sheet lead held on with a pin or thread, but it must have just a certain

weight, determined by clipping it down to the most effective size, and it must be attached beneath a point near the centre of the thorax.

From the performance of this model we may conclude that two conditions are essential to make gliding possible, aside from the possession of a glider apparatus. The first condition demands that the centre of gravity be in the region of the body supporting the glider lobes; the second, that the creature must have the ability to project itself into the air. We would draw the inference, therefore, that insects equipped with glider lobes, if the lobes were confined to the thorax, had slender abdomens and carried the weight of their viscera more evenly distributed in the body than do many of the more specialised insects of the present time, and furthermore, that the gliding insects had well-developed legs which enabled them to run swiftly off the end of a support, or to launch themselves into the air by a vigorous leap. Many of the modern grasshoppers do not depart far from this primitive mode of flight, except in that they combine an excellent pair of saltatorial legs with a pair of expansive sails that can perform also, in a weak manner, as organs of true flight.

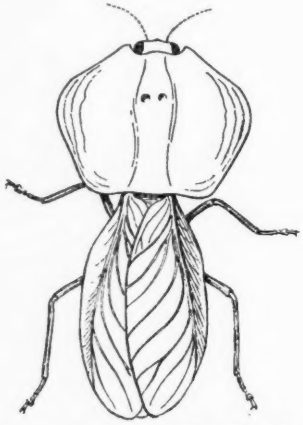

FIG. 5.—A mantis from Ecuador with large lateral extensions of the back plate of the prothorax.

The question always arises, or is deliberately brought up to embarrass every speculation in evolution, as to how organs could have been evolved in their earlier stages when they were too small to serve any specific function; and if we cannot answer this question it is taken to invalidate the assumption implied by the theory. Certainly, paranotal lobes on the thorax could not have had any locomotory function until they were large enough to serve as gliders. And yet, many modern insects have lateral extensions of the back plate of the prothorax, such as occur frequently in the beetles, which appear to be of no particular use to their possessors, and in some species of mantids the back plate of the prothorax is expanded into a large, flat shield. (Fig. 5.) Utility probably guides the course of an organ's evolution, but it does not necessarily determine its inception. Specific structures may develop for no practical reason at all. Some writers have supposed that the paranotal lobes of insects served first as gills for breathing in the water but this theory must assume that insects had an aquatic stage in their phylogeny, of which there is no evidence.

There are existing to-day certain small insects, known as the Apterygota because they not only lack wings but they contain no evidence in their body

structure of being descended from winged ancestors. They are apparently direct descendants of the unknown, primitive, wingless progenitors of all the insects. Indirectly the Apterygota furnish evidence of the evolution of wings in the winged insects, or Pterygota, from paranotal lobes. The Pterygota are characterised by a special type of structure in the plates forming the lateral, or pleural, walls of the thoracic segments, the pleural structure being essentially the same in the wingless prothorax as in the two wing-bearing segments. In the Apterygota the corresponding plates are quite different from those of the winged insects, and differ much in the several apterygote families. We must conclude, therefore, that the peculiar structure of the pleural walls of the thoracic segments in the Pterygota, and their basic uniformity in the three segments of the thorax means that the walls of these segments once served a common purpose. This purpose evidently was the support of a pair of paranotal lobes on each thoracic segment. (Fig. 6.) The lack of pleural plates in the lateral walls of the abdominal segments similar to those of the thorax suggests that paranotal lobes of the abdomen, if present, never reached a size of functional importance.

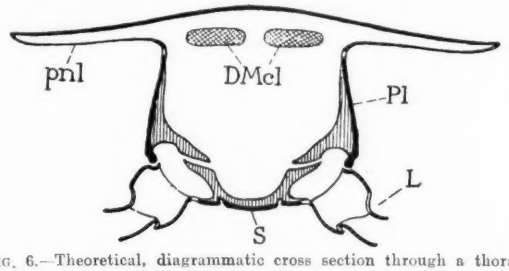

FIG. 6.—Theoretical, diagrammatic cross section through a thoracic segment of a hypothetical insect with paranotal, or glider, lobes in place of wings. *DMcl*, Dorsal longitudinal, intersegmental muscles; *L*, base of leg; *Pl*, pleuron; *pnl*, paranotal lobe; *S*, Sternum.

II. Structure of the Wings

It is a long way from immovable paranotal lobes to fully developed wings capable of sustained flight. In the first step toward the status of wings, the paranotal lobes of insects had simultaneously to become flexible at their bases and to acquire a motor mechanism that would impart to them the movements necessary in organs of flight. Flight, it must be observed, is not to be accomplished by a mere up-and-down flapping of a pair of flat appendages; as will be explained later, in order to generate forward motion, wings must be capable not only of movements in a vertical direction, but also of some degree of anterior and posterior movement accompanied by a partial rotation on their long axes. The mechanism of an insect's wings, therefore, must be such as to produce at least the movements necessary for progression in the air. Insects that fly most efficiently, however, have evolved an apparatus capable also of controlled flight, of sidewise flight, of rearward flight, and of hovering. Finally, to this equipment most insects have added a special mechanism for folding the wings horizontally over the body when not in use.

Winged insects may be divided into those that keep the wings extended straight out at the sides when at rest, or which merely close them vertically over the back, and those that fold the wings horizontally over the body. Among modern insects, the first group is represented by the dragon flies (Figs. 7 and 8) and the May flies (Fig. 9); the second includes most of the other insects. In the Paleozoic era, the insects that did not fold the wings included the dragon flies and May flies of that time, and also the members of the Paleodictyoptera, so far as can be judged from their fossil remains. These insects were inhabitants

of the open, watery spaces, and probably used their legs principally for perching; they had no occasion for crawling about in places where spread wings would be an encumbrance to their movements. Their general habits were evidently similar to those of the modern May flies and dragon flies, and in their younger stages they probably lived in the water as do at present the members of these two groups of insects. The ancient insects that folded their wings horizontally over the back when not in use included the roaches and various forms that appear to be representative of several other modern orders of wing-folding insects. The roaches at least were inhabitants of the forests, adapted to living in the matted vegetational débris of the forest floor, on the scaly-barked trees, or between the bases of their frond-like leaves.

The dragon flies belong to the order Odonata, but there are two distinct suborders of them. One suborder, known as the Anisoptera, includes the ordinary large species, or true dragon flies (Fig. 7), which, when at rest, keep the wings

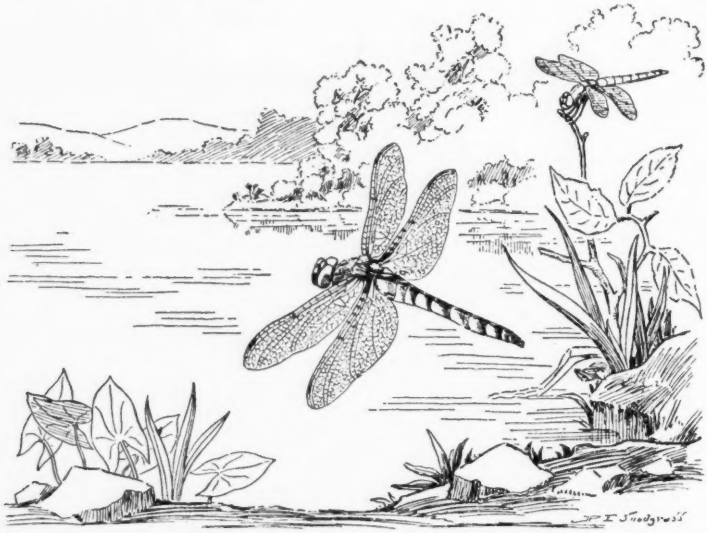

FIG. 7.—Dragon flies of the suborder Anisoptera. When the insects are perched, the wings are held horizontally at right angles to the body.

spread straight out at the sides of the body. The other suborder is the Zygoptera and includes species generally smaller in size which, when at rest, fold the wings over the back with the dorsal surfaces together. (Fig. 8.) Members of the Zygoptera are sometimes distinguished as damsel flies; most of them are rather weak creatures with long, slim abdomens and slender wings narrowed at the bases. They are comparatively feeble fliers and are easily caught. The true dragon flies of the suborder Anisoptera are subdivided into two families, the Libellulidæ and the Aeschnidæ. The libellulids are the common dragon flies seen about streams and pools, where they perch on the ends of twigs from which they dart out on vigorous short flights in pursuit of some small passing insect. The æschnids include those large species that we used to call devil's darning needles. They are most efficient fliers, being seldom seen to alight anywhere as they go skimming above the surface of the water, and they often make long excursions inland, appearing in places where a dragon fly is least expected. So agile are they on the wing that the collector must sometimes resort to the gun and bird-shot to procure specimens of them.

The May flies are members of the order Ephemerida. They are mostly fragile, short-lived creatures in the adult stage, and when at rest fold the wings straight up over the back with the dorsal surfaces together. (Fig. 9.)

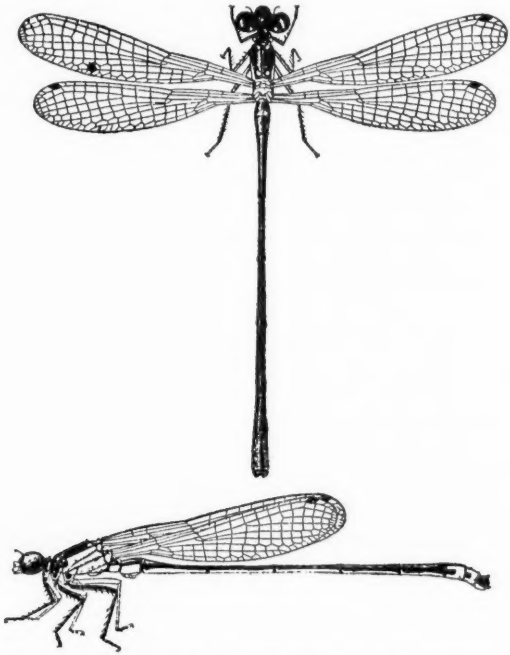

FIG. 8.—Dragon flies of the suborder Zygoptera, called damsel flies which, when at rest, fold the wings in a vertical plane over the back (*Ischnura cercula*, from Kennedy).

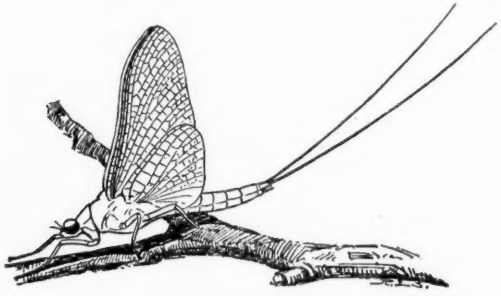

FIG. 9.—A May fly, a member of the order Ephemerida. When at rest the wings are folded vertically over the back.

All other modern winged insects, with a few exceptions such as the butterflies, fold the wings posteriorly and horizontally over the body when they are not in use. This manner of folding the wings may be distinguished as flexion. It is quite different from the other, in which the extended wings are merely brought together vertically over the back, and it involves the presence of a special mechanism of flexion which the dragon flies and May flies do not possess.

Since the wing-flexor apparatus has very evidently been added to that which produces the movements of flight, it is usually supposed that the insects which do not flex the wings are descendants of a more primitive group of ancestral insects than are those which flex the wings. The fundamental structure of the wings we might suspect, therefore, would be best preserved in the wings of the dragon flies and May flies; but it is certain that these insects, though of relatively primitive origin, have developed many specialised characters of their own. Particularly is this true of the dragon flies. The structure of a " generalised " wing, then, is to be judged rather from the *ensemble* of the wing characters in all insects than from a study of the wings of any particular group of insects.

The general wing mechanism, including the muscles that generate and regulate the wing movements, will be described in following sections. To understand how the motor elements give the essential movements of flight to the wings, it will be necessary first to know something of the structure of the wings themselves and the details of their connections with the body. The principal features of the wings are the veins, the articulation to the body, the flexor apparatus, and the differentiation of the wing area into special regions in insects that flex the wings.

The wing veins.—The wings of adult insects are thin, membranous extensions of the body wall strengthened by the rib-like thickenings known as veins. (Fig. 10.) The principal veins of each wing spring from the wing base and branch in varying degrees in the distal parts of the wing. The work of many entomologists has shown that, underlying the great diversity of vein pattern in the numerous groups of insects, there is evidently one fundamental plan of wing venation. All winged insects, therefore, would appear to be derived from one primitive stock that evolved the paranotal lobes into movable organs of flight.

The system of naming the principal veins now commonly adopted, with a few alterations, by nearly all entomologists is that worked out by Comstock and Needham, shown diagrammatically in Fig. 10 A. The first vein is the *costa* (*C*); it usually forms the anterior margin of the wing, but sometimes it is submarginal. The second vein is the *subcosta* (*Sc*), typically forked into two short branches. The third vein is the *radius* (*R*), usually the strongest vein of the wing; distally it forks near the middle of the wing, and the posterior prong (*Rs*) breaks up into four branches. The fourth vein is the *media* (*M*), forked dichotomously into four principal branches. The fifth vein is the *cubitus* (*Cu*), with two branches. The rest of the wing veins, according to the Comstock-Needham system of vein nomenclature, are the *anal veins*, distinguished as the *first anal* (1*A*), *second anal* (2*A*), etc.

There are certain objections to including all the veins posterior to the cubitus under the one term " anal." In the first place, the so-called first anal is found to be in some cases a basal branch of the cubitus, and for this reason Tillyard (1919) has renamed it the second branch of the cubitus, and Karny (1925) terms it the cubital sector. In other insects, however, the same vein apparently has no basal connections in the adult wing, and the writer (1929), for convenience, has called it the *second cubitus*. (Fig. 10 B 2*Cu*.) In any case, this vein has no relationship with the other so-called anal veins; the latter (Fig. 10 A, 2*A*, 3*A*, etc.) constitute a natural group of veins in the posterior part of the wing associated with the third articular sclerite of the wing base (B, 3*Ax*). Since the wing area supported by these veins is often expanded into a large, fan-like region, the writer (1929) has suggested calling the veins of this region the *vannal veins* (Latin *vannus*, a fan), distinguishing them individually as the *first vannal* (Fig. 10 B, 1*V*), *second vannal* (2*V*), etc.

The innermost part of the wing proximal to the region of the vannal veins is often differentiated as a lobe, or a distinct part of the wing, designated by Martynov (1925) the *jugal region* because in the fore wing it sometimes bears a small lobe, or jugum, serving to yoke the fore and hind wings together. In

this region there is sometimes a network of irregular veins, but again the jugal region may contain one or two quite definite veins, named the *vena arcuata* (Fig. 10 B, *Va*) and *vena cardinalis* (*Vc*) by Martynov.

The area of the wing containing the veins may be thus divided, especially in the wing-flexing insects, into three regions. The first is the prevannal region,

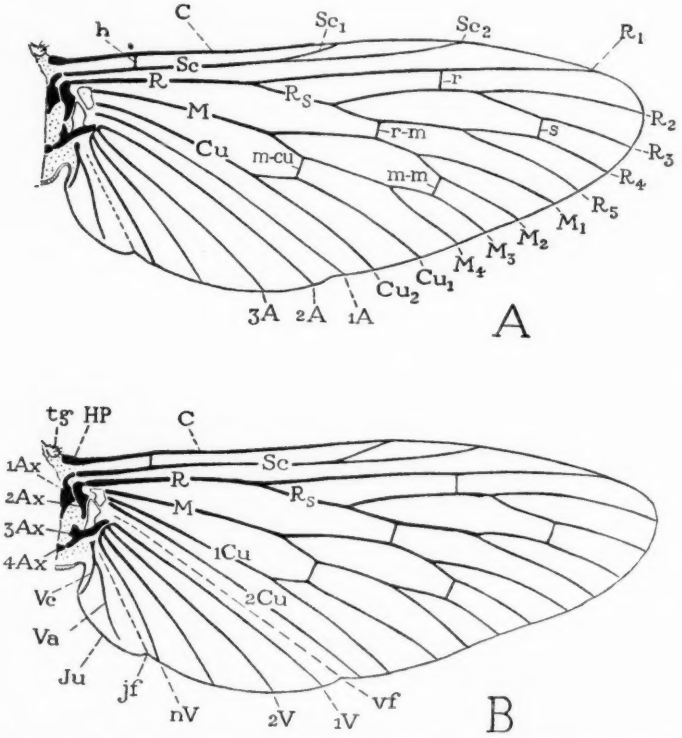

FIG. 10.—The veins and articular sclerites of the wing of an insect that folds the wings horizontally over the back. A, Diagram of a wing with the veins named according to the Comstock-Needham system; 1A, 2A, first and second anal veins; *C*, costa; *Cu*, cubitus; Cu_1, Cu_2, branches of cubitus; *h*, humeral cross vein; *M*, media; M_1–M_4, branches of media; *m-cu*, medio-cubital cross vein; *m-m*, median cross vein; *R*, radius; R_s, radial sector; R_1–R_5, branches of radius; *r*, radial cross vein; *Sc*, subcosta; Sc_1–Sc_2, branches of subcosta. B, Nomenclature of the veins and articular sclerites used in this paper; 1*Ax*, 2*Ax*, 3*Ax*, 4*Ax*, first, second, third, and fourth axillary sclerites; 1*Cu*, first cubitus (*Cu* of A); 2*Cu*, second cubitus (1A of A); *HP*, humeral plate; *jf*, jugal fold, plica jugalis; *Ju*, jugal region; 1*V*, first vannal vein (2A of A); 2*V*–*nV*, second to last vannal veins; *tg*, rudiment of tegula; *Va*, vena arcuata; *Vc*, vena cardinalis; *vf*, vannal fold, plica vannalis.

or remigium, the second is the vannal region, the third the jugal region. (Fig. 14.) The remigium and the vannus are often separated by a vannal fold, or *plica vannalis* (Fig. 10 B, *vf*), while the vannal and jugal regions are separated by a jugal fold, or *plica jugalis* (*jf*). The vannal fold, however, is sometimes doubly plicate, and a secondary vein, the *vena dividens* (Fig. 15 B, *Vd*), then lies between the two lines of plication. This concept of the structure of the posterior part of the wing will at least serve for purposes of description in the

present paper, but it is possible that a more comprehensive study of the wing in generalised insects will reveal that we do not yet understand the true homologies of the veins in the post-cubital region.

All the veins of the wing are subject to secondary forking and to union by cross veins. In some orders of insects the cross veins are so numerous that the whole venational pattern becomes a close network of veins and cross veins.

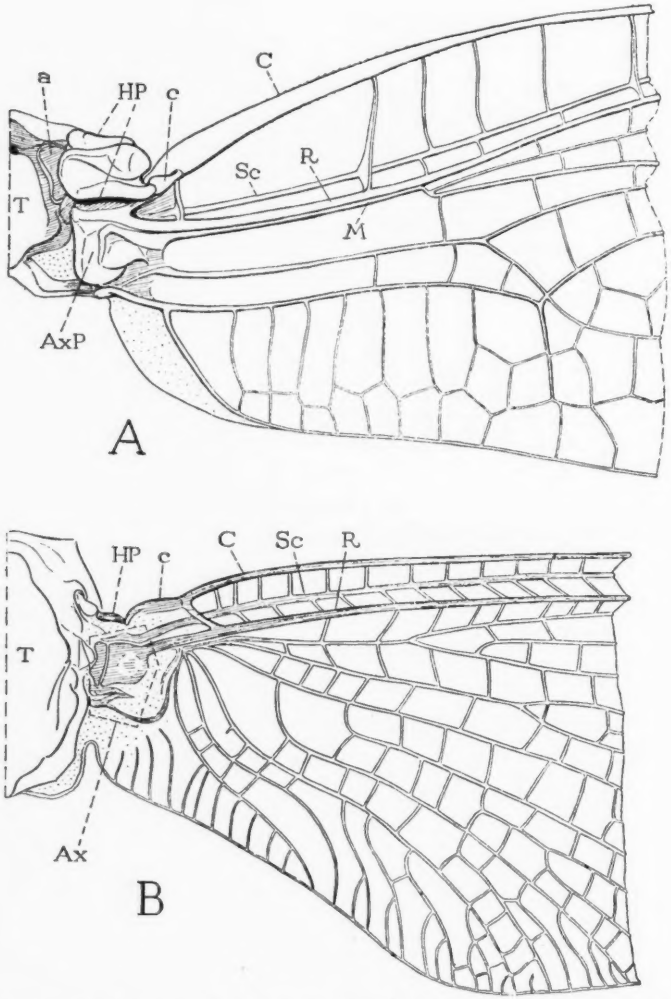

FIG. 11.—Basal structure of wing of a dragon fly and a May fly, insects that do not flex the wings posteriorly over the back. A, Basal part of forewing of a dragon fly (*Anax junius*); *a*, detached plate of tergum; *AxP*, axillary plate; *C*, costa; *c*, small sclerite at base of costa; *HP*, humeral plate; *M*, media; *R*, radius; *Sc*, subcosta; *T*, tergum. B, basal part of forewing of a May fly; *Ax*, axillary region corresponding with axillary plate of dragon fly's wing (*AxP* of A); other lettering as on A.

(Figs. 7, 8, and 9.) Ordinarily, however, there is a definite number of cross veins having specific locations as indicated in the diagram. (Fig. 10 A.)

Articulation of the wings.—The simplest structure in the articular parts of the wing is that shown by the dragon flies and May flies, since the wings of these insects are adapted to movements of flight only, and, as a consequence, possess only the flight mechanism. In the wings of insects that flex the wings, there is superadded to the apparatus of flight a mechanism for folding the wings. The dragon flies and May flies are commonly regarded as being descendants of a more primitive ancestral stock than that of the wing-flexing insects; but the question as to whether their articular mechanism is primitive, or derived from a more complicated mechanism, will not be discussed here. The dragon fly wing base may be taken as a starting point in a descriptive sequence, however, because of its simplicity.

Each wing of a dragon fly is attached to the body by two large basal plates. (Fig. 11 A). The first plate we may call the *humeral plate* (*HP*), the second the *axillary plate* (*AxP*). The humeral plate, though as large as the other, bears only the first vein of the wing (*C*), which has a small, intermediary piece (*c*) at its base. The axillary plate carries the four basal shafts of the other wing veins, which are all directly attached to it. The humeral plate is hinged to the anterior half of the lateral edge of the tergum, or back plate (*T*), of the segment supporting the wings, or sometimes to a distinct sclerite (*a*) of the tergum. The axillary plate is articulated to the posterior half of the lateral tergal margin opposite a deep membranous area of the latter. The wing base is supported from below by the wing process of the pleural wall of the segment, one branch of it articulating with the humeral plate, another with the axillary plate.

The basal plates of the dragon fly's wing turn up and down on the fulcral arms when the wings are lifted or depressed. The two plates, however, are slightly movable on each other, and, since the costal vein (*C*) is doubly hinged to the humeral plate by the small intermediary piece (*c*) at its base, the costal area of the wing can be quite freely deflected independent of the rest of the wing area, which is solidly supported on the axillary plate by the veins attached to the latter.

The May flies, or Ephemerida, are the only other order of modern insects that do not flex the wings. At first sight the base of the May fly's wing (Fig. 11 B) appears to have little in common with that of the dragon fly (A). On closer inspection, however, it is seen that the chief difference consists of a great reduction in size of the humeral plate (*HP*), and a breaking up of the region of the axillary plate (*AxP*) into a number of irregular sclerotisations. The humeral plate (*HP*) becomes a small sclerite on the anterior margin of the wing base intermediating between the base of the costal vein (*C*) and a small lobe of the dorsal wall of the segment supporting the wing. The small plates of the axillary region (*Ax*) in the May fly suggest, as we shall presently see, the definite sclerites of the flexor mechanism in insects that fold the wings horizontally over the back.

In all insects that flex the wings, the major part of the wing base is occupied by a number of small sclerites which lie between the edge of the supporting tergum and the proximal ends of the veins. These axillary sclerites, or *axillaries* (Fig. 12), have definite and constant relations not only to the tergum and the veins, but also to one another, though they vary much in details of form, and certain pieces are sometimes lacking. Three sclerites, however, are practically always present (*1Ax*, *2Ax*, *3Ax*), and in some insects there is a fourth (Fig. 10 B, *4Ax*), while at least one or two accessory plates (Fig. 12, *m*, *m'*) are usually associated with the more constant sclerites. The humeral plate of the wing base is generally small (*HP*), and may be absent, but it is often relatively large though never attaining the size it has in the wing of a dragon fly (Fig. 11 A, *HP*). When the humeral plate is present the costal vein (*C*) is associated with it. The other veins are related to the sclerites of the true axillary region.

The axillary sclerites have in general the following characteristics and relationships: The *first axillary* (Fig. 12, *1Ax*) lies next to the body in the anterior part of the axillary region of the wing base, and is articulated by a longitudinal hinge to the edge of the tergum (*T*). Its anterior end is curved outward and usually is connected with the base of the subcostal vein (*Sc*). The *second axillary* (*2Ax*) lies distal to the first, and is obliquely hinged to the outer edge of the latter. This sclerite is the pivotal plate of the wing base since its ventral surface rests upon the pleural wing process. (Fig. 13, *WP*.) The radial vein (Fig. 12, *R*) is flexibly attached to its outer end, and the point of union (*d*) constitutes the principal hinge of the anterior part of the wing with the axillary elements. The *third axillary* (*3Ax*) lies posterior to the other two with its long axis transverse. Its proximal end articulates with the tergum, and its distal

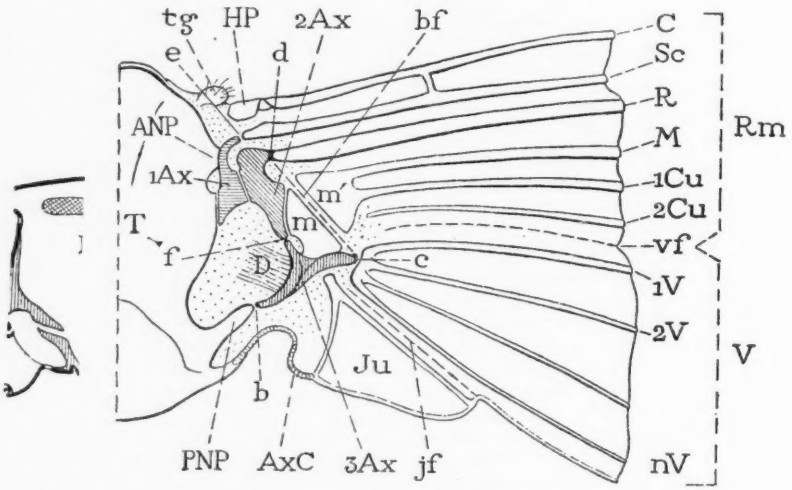

FIG. 12.—Diagram of basal structure of wing in wing-flexing insects. *ANP*, Anterior notal wing process; *1Ax*, *2Ax*, *3Ax*, first, second, and third axillaries; *AxC*, axillary cord; *b*, articulation of third axillary with tergum; *bf*, basal fold wing, plica basalis; *C*, costa; *c*, distal end of third axillary; *1Cu*, first cubitus; *2Cu*, second cubitus; *D*, flexor muscle; *d*, articulation of radius with second axillary; *e*, articulation of subcosta with first axillary; *f*, articulation of third axillary with second axillary; *HP*, humeral plate; *jf*, jugal fold of wing, plica jugalis; *Ju*, jugal region; *M*, media; *m*, proximal median plate; *m'*, distal median plate; *nV*, last vannal vein; *PNP*, posterior notal wing process; *R*, radius; *Rm*, remigial part of wing; *Sc*, subcosta; *T*, tergum; *tg*, rudiment of tegula; *V*, vannal part of wing; *1V*, *2V-nV*, first to last vannal veins; *vf*, vannal fold of wing, plica vannalis.

extremity supports the bases of the posterior group of wing veins (*V*). A process on the basal part of the third axillary gives insertion to a muscle (*D*) which arises on the lateral wall of the segment. The third axillary and its muscle constitute the motor elements in the flexor mechanism of the wing. When a *fourth axillary* is present it intervenes between the base of the third and the tergum. In the distal part of the axillary region there are usually one or more accessory *median plates* (*m*, *m'*) associated with the bases of the median and cubital veins. The median plates are more variable than the well-defined axillaries; the proximal one (*m*) is usually attached to the distal part of the third axillary.

Since the wing is a double-walled fold projecting from the body, its basal part (Fig. 12) is two-layered, one layer being continuous with the tergal wall of the segment, the other with the pleural wall. The axillary sclerites are contained in this articular region. On the humeral angle of the latter is a small lobe (*tg*), in some insects developed into a scale overlapping the wing base, and known as the tegula. The posterior part of the wing base is membranous, and its posterior border is thickened and corrugated, giving the appearance of a marginal ligament, or *axillary cord* (*AxC*), continued from the posterior angle of the tergum a varying distance into the posterior margin of the wing.

The ventral support of the wing is the same in all insects, consisting of the pleural wing process (Fig. 13, *WP*) which rises from the pleural wall of the

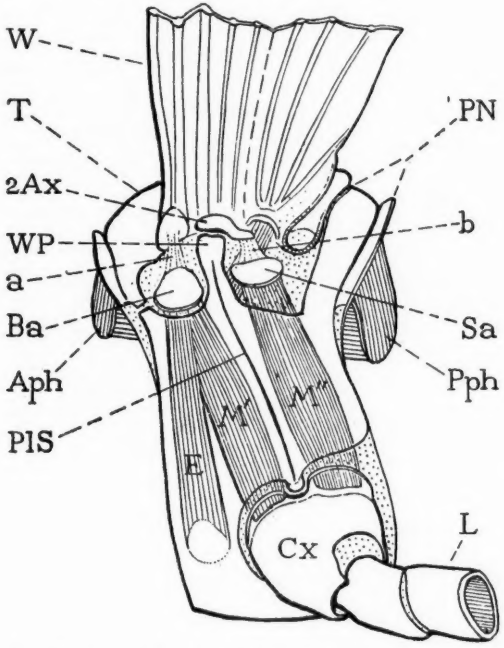

FIG. 13.—Diagram of the pleural elements of the wing mechanism, left side of a segment. *a*, Membranous connection of basalar sclerite (*Ba*) with anterior angle of wing base; *Aph*, anterior phragma; *2Ax*, ventral plate of second axillary; *b*, membranous connection of subalar sclerite (*Sa*) with second axillary (*2Ax*); *Ba*, basalare; *Cx*, coxa; *E*, pleural muscle of basalare; *M'*, coxal muscle of basalare; *M''*, coxal muscle of subalare; *PlS*, pleural suture; *PN*, postnotum; *Pph*, posterior phragma; *Sa*, subalare; *W*, base of wing, elevated; *WP*, *pleura wing process*.

segment and forms a fulcrum for the wing base. In insects that have axillary sclerites, the second axillary (*2Ax*) rests directly upon the wing process. Lying in the membrane beneath the wing base, anterior and posterior to the fulcrum, are usually two sclerites (*Ba*, *Sa*) intimately associated with the wing. The first is the *basalare* (*Ba*), the second the *subalare* (*Sa*). Both sclerites are derived, not from the wing, but from the upper edge of the pleural wall, and in some adult insects the basalare remains as a partly-detached lobe of the latter. These two epipleural plates are important elements of the wing mechanism, for,

as we shall see, they form insertion points for two large wing muscles. The basalare is connected by a ligamentous thickening (*a*) of the membrane beneath the wing base with the humeral angle of the wing; the subalare is similarly connected (*b*) with the second axillary sclerite.

The wing regions.—The wings of all insects are more or less asymmetrical in form; not only is the front margin of each wing always of a different contour from the hind margin, but the pattern of the anterior veins never matches that of the posterior veins. There is a tendency for the anterior veins to become crowded toward the forward margin in such a manner as to give rigidity to the front half of the wing, while the posterior veins are more widely spaced—allowing of a flexibility in the rear half of the wing. This arrangement of the veins, together with the antero-posterior difference in the form of the wing, is clearly an adaptation for giving greater efficiency to the wings as organs of forward flight, notwithstanding the fact that many insects can fly backward and sidewise. As a result of the functional differences in the parts of the wing, the wing area

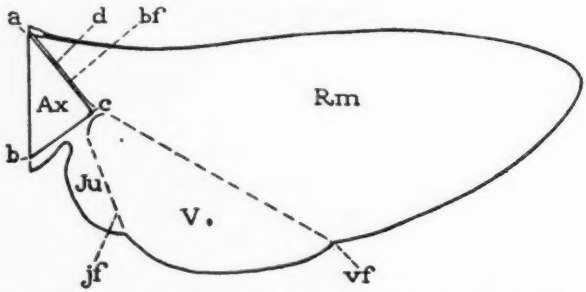

FIG. 14.—Principal wing regions in insects that flex the wings. *a–b*, Base of axillary region; *Ax*, axillary region; *bf*, basal fold of wing, plica basalis; *c*, apex of axillary region; *d*, point of articulation of radia vein with second axillary (see Fig. 12); *jf*, jugal fold, plica jugalis; *Ju*, jugal region; *Rm*, remigium, remigial region; *V*, vannus, vannal region; *vf*, vannal fold, plica vannalis.

becomes differentiated structurally into several regions. The wing regions are particularly well defined in insects that flex the wings, because the wing folding could not be allowed to interfere with the function of flying, and, therefore, the adaptations for flexing have to follow the structural plan primarily laid down for purposes of flight.

We have already seen that there is at the base of each wing an axillary region, represented by the second plate of the dragon fly's wing (Fig. 11 A, *AxP*), which becomes broken up into a number of definite axillary sclerites in the wing-flexing insects (Fig. 12). The region of the axillary sclerites has in general the form of a scalene triangle (Fig. 14, *Ax*) with its base (*a*—*b*) against the body and its longer side anterior to the apex (*c*). The base of the triangle is the hinge of the wing with the body; the apex represents the distal end of the third axillary sclerite (Fig. 12, 3*Ax*), which carries the bases of the vannal veins; the point *d* on the anterior side of the triangle (Fig. 14) marks the articulation of the radial vein (Fig. 12, *R*) with the second axillary sclerite (2*Ax*). The rôle that the axillary triangle plays in the folding of the wing will be discussed in Section IV of this paper.

The area of the wing distal to the axillary region comprises the three parts of the wing separated by the vannal and jugal folds (Fig. 10 B, *vf*, *jf*), when these folds are present. The area anterior to the vannal fold (Fig. 14, *Rm*), containing the costal, subcostal, radial, medial, and cubital veins (Fig. 10 B), is

the part of the wing chiefly productive of the movements of flight, since it is directly affected by the motor-wing muscles. This part of the wing, therefore, we may term the *remigial area* of the wing (Latin remigium, an oar). The region between the vannal and jugal folds is the part of the wing here termed the *vannus*, or vannal region (Fig. 14, *V*), though ordinarily called the anal region. The vannal veins typically spread out like the ribs of a fan, and, as we have seen, their bases are associated with, or supported by, the distal end of the third axillary sclerite. (Fig. 10 B). In some insects the vannus becomes so large, as in the hind wings of grasshoppers and katydids (Fig. 15 B), that it

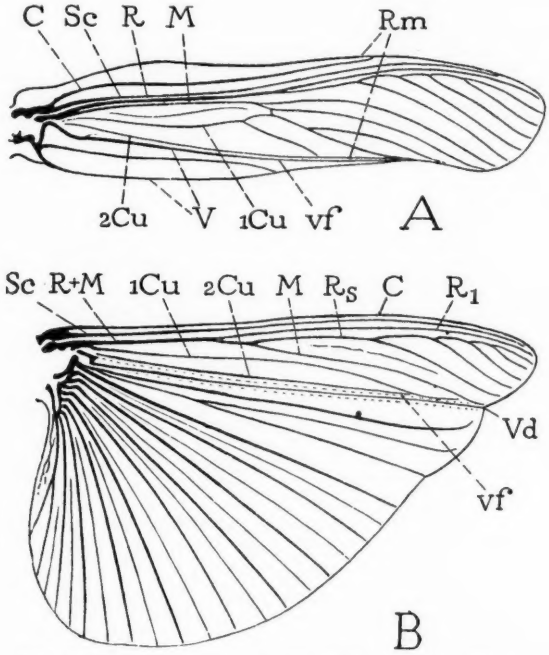

FIG. 15.—The wings of a grasshopper (*Dissosteira carolina*). A, Left forewing. B, Left hind wing. Lettering as on Fig. 10B. The great fan of the hind wing posterior to the vannal fold (vf) is possibly the combined vannal and jugal regions.

forms an efficient gliding surface which enables the insects to sail through the air with comparatively little movement of the wings. Proximal to the vannus is the *jugal region* (Fig. 14, *Ju*), usually a small membranous area or lobe at the base of the wing, but sometimes much enlarged (Fig. 16).

III. The Wing Muscles

The musculature of an insect's wing is very simple, considering the nature of the wing movements and the fine adjustments of the latter that the muscles are able to produce. The effect of the muscles on the wings depends largely on the manner in which the wings are attached to the body and on the details of structure in the wings themselves.

In the majority of insects, all the movements of the wings are accomplished by five principal pairs, or paired sets, of muscles in each wing segment.

Anatomically the wing muscles belong to three groups, namely, dorsal longitudinal muscles, tergo-sternal muscles, and pleural muscles. Considering the manner in which they effect movement in the wings, however, they are usually classed as "indirect wing muscles" and "direct wing muscles," the first class being the dorsal and tergo-sternal muscles, the second the pleural muscles. Functionally, each of the five sets of muscles must be considered individually.

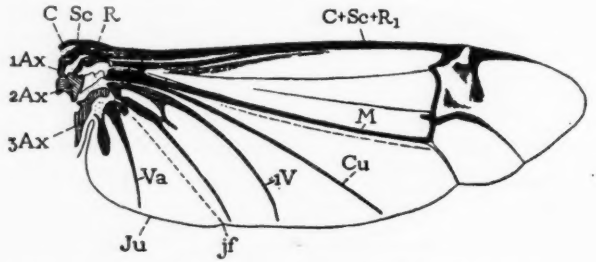

FIG. 16.—Hind wing of a blister beetle (*Epicauta marginata*), showing the large jugal region (*Ju*).

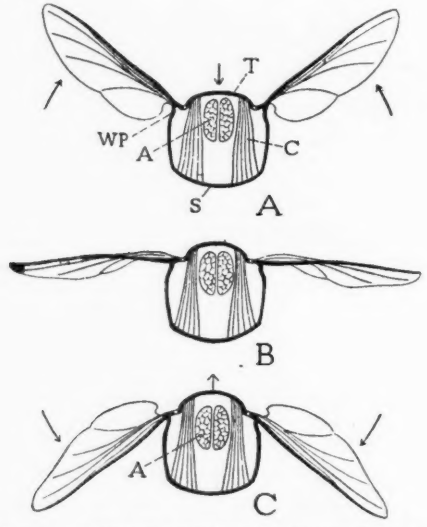

FIG. 17.—Diagrams suggesting the indirect action of the segmental muscles on the wings, and the torsion of the wings in flight, anterior view. A, The wings elevated on pleural wing processes (*WP*) by depression of tergum (*T*) caused by contraction of tergo-sternal muscles (*C*); hind margins of wings deflected. B, C, The wings depressed by an elevation of tergum caused by contraction of dorsal longitudinal muscles (*A*); hind margins of wings elevated.

If the wings of insects originated, as we have supposed, from movable flaps of the body wall extending laterally from the edges of the back plates of the body (Fig. 6), they had primarily at their disposal, for motor purposes, only the muscles of the body segments supporting them. These muscles comprised the

longitudinal intersegmental muscles, and possibly dorsoventral intrasegmental muscles. The dorsal longitudinal muscles, by pulling lengthwise on the back-plates, could arch these plates upward between the two ends in each segment. Thus, considering that the wing lobes were extensions of the terga, and were supported near their bases on the upper edges of the pleural walls of the segment, each lobe could be given a downward movement by an upward flexure of the tergum just as a pump handle might be lowered by raising the piston. All modern insects, with a few exceptions, produce the downstroke of the wings at least in part by the contraction of the dorsal thoracic muscles. (Fig. 17 C, *A*.) In response to the new function thus thrust upon them, these muscles in the two wing-bearing segments have become greatly enlarged. (Fig. 18—81, 112.) The

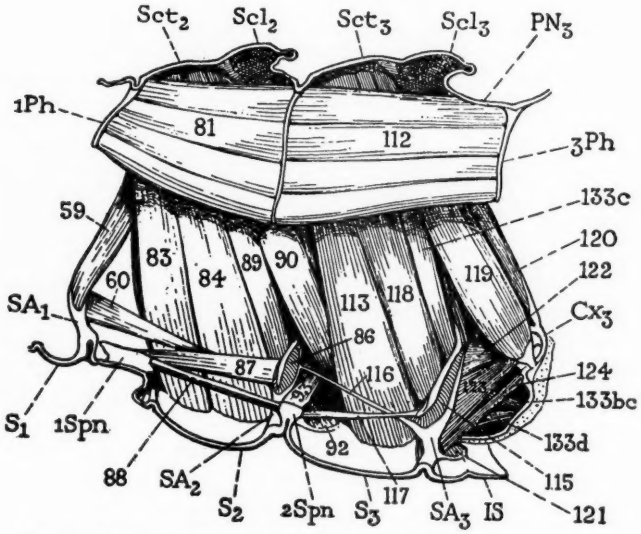

FIG. 18.—Muscles in the right half of the wing-bearing segments of a grasshopper (*Dissosteira*) as seen from the median plane of the body. 81 112, The longitudinal dorsal muscles which, by contraction, arch the terga plates upward and thereby depress the wings; 83, 84, and 113, the tergo-sternal depressors of the tergal plates, which indirectly elevate the wings. The other muscles are muscles of the legs and of the sterna.

elevation of the wings, on the other hand (Fig. 17 A), involves a depression of the back plate (*T*) of the wing-supporting segment, and this is accomplished by a contraction of the vertical, or tergo-sternal, muscles of the segment (*C*), just as the pump handle might be raised by pulling down on the piston. It is a question whether the tergo-sternal muscles of the wing-bearing segments were a part of the primitive musculature of the segments, or whether they are specially acquired wing muscles; but, whatever their origin, they are always very large in the two segments (mesothorax and metathorax) that carry the wings (Fig. 18—83, 84, 113), while they are either absent or doubtfully represented in other segments of the body.

The segmental muscles that move the wings owe their efficiency to the fact that each wing is pivoted a short distance beyond its base on a strong fulcrum of the lateral wall of the segment. (Fig. 17 A, *WP*.) The degree of movement in the back plate, or tergum (*T*), of the segment necessary to produce the up-and-down strokes of the wings is very small. In freshly-killed specimens of flies

and bees the wings respond instantly to the least downward pressure on the back of the segment, or to a gentle lengthwise compression of the thorax.

True flight, as we have already observed, is not to be accomplished by mere upstrokes and downstrokes of the wings. Each wing must have a propeller movement in order to produce motion through the air; the plane of the wing must dip forward and downward with each downstroke (Fig. 17 C), and must then reverse itself during the upstroke (A). The ability of the insect wing to make these compound movements depends in part upon the interrelations of the articular sclerites, and in part on the structure of the wing itself. The anterior crowding of the principal wing veins stiffens the forward part of the wing and leaves the expanded posterior area relatively weak and flexible. When the wing is depressed, therefore, its posterior part turns upward (Fig. 17 C) as a result of the increased air pressure below, and thus gives a forward thrust to the wing, with the result that the anterior margin goes downward and forward. For the same reasons the counterstroke has a reverse movement (A).

It is possible that the structure of the wing and its automatic response to air pressure enabled the primitive winged insects to fly by means of the dorsal and tergo-sternal segmental musculature alone. Nearly all modern insects, however, have powerful adjuncts to the primitive motor mechanism of the wings in the pleural muscles that affect directly the movements of each wing. These so-called " direct " wing muscles (Fig. 19, *E*, *M'*, *M''*) are inserted in adult insects either immediately on the wing bases or on the small sclerites beneath the wings (Figs. 13, 19, *Ba*, *Sa*) or, in some cases, on a lobe of the lateral wall of the segment; they have their origins, in nearly all cases, on the pleura and on the basal segments, or coxæ, of the legs (Fig. 19, *Cx*). In the young of insects that resemble the adults in bodily form, however, these same muscles are inserted on the dorsal edges of the lateral walls of the wing-bearing segments. It appears highly probable, therefore, that the coxal basalar and subalar wing muscles of adult insects are in origin leg muscles that have been given over to the service of the wings. The function of these muscles will be more particularly described in the following section.

The muscle of the basalar sclerite arising on the coxa (Fig. 19, *M'*) is usually supplemented by a branch or a second muscle (*E*) arising on the lateral wall of the segment, or on the sternum. The basalar sclerite, as we have seen, is intimately attached to the humeral angle of the wing base by a thickening (*a*) of the intervening membrane. The subalar muscle (Fig. 19, *M''*) is always a large muscle, and through the attachment (*b*) of the subalar sclerite with the secondary axillary sclerite of the wing base (*2Ax*) it pulls downward on the base of the wing immediately behind the fulcral support (*WP*).

In the dragon flies the homologues of the basalar and subalar muscles of other insects are inserted by strong " tendons " that are attached directly on the wing bases, the first on the humeral plate (Fig. 11 A, *HP*), the second on the axillary plate (*AxP*). Furthermore, the ventral ends of these muscles in the dragon flies take their origin on the lower edge of the pleural wall of the segment, their bases evidently having been transferred from the coxa to the body wall. In the flies (Diptera) the base of the subalar muscle has undergone a similar transposition.

The fifth set of wing muscles are the wing flexors. The flexor of each wing is usually a small muscle, or a group of small muscles (Fig. 19, *D*), the fibres of which have their origin on the pleural wall of the segment and are inserted directly on the third axillary sclerite of the wing base (Fig. 12, *3Ax*). The flexor muscles are present in nearly all insects, including the dragon flies which do not fold the wings; in insects having a special flexor mechanism in the wing base they appear to accomplish the entire movement of flexion.

Various other small muscles are often associated with the wings; they arise on the upper parts of the pleural walls of the wing-bearing segments and are

inserted either on the tergum near the wings or directly on the wing bases. Since these muscles are not of constant occurrence and differ in different groups of insects, they need not be considered in a general discussion.

IV. The Wing Movements

The motions of insects' wings fall into two distinct categories; those of one include the movements of flight, those of the second embrace the movements of flexion and extension. The flight movements are common to all winged insects; the movements of flexion and extension pertain only to insects that fold the wings horizontally over the back when not in use.

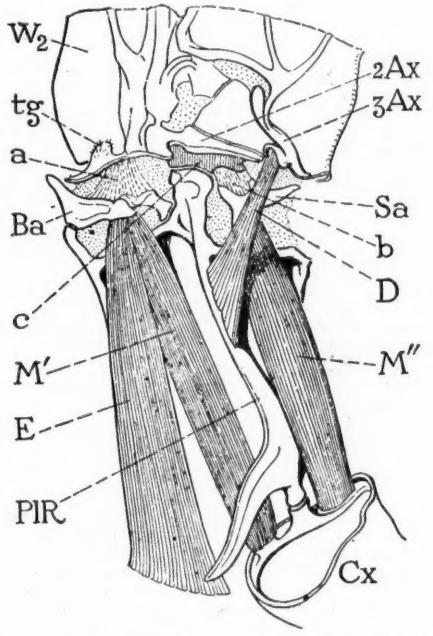

FIG. 19.—The pleural wing muscles of the mesothorax of a grasshopper (*Dissosteira*), inner view of right side. *a*, Membranous connection of basalar sclerites (*Ba*) with humeral angle of wing base; 2*Ax*, dorsal plate of second axillary; 3*Ax*, third axillary; *b*, connection of subalare (*Sa*) with second axillary; *Ba*, basalar sclerites; *c*, ventral plate of second axillary; *Cx*, coxa; *D*, flexor muscle of wing; *E*, pleural basalar muscle; *M'*, coxo-basalar muscle; *M''*, coxo-subalar muscle; *PlR*, pleural ridge; *Sa*, subalare; *tg*, rudiment of tegula; W_2, mesothoracic wing, turned upward.

The movements of flight.—The movements of the wings that make flight possible consist of an *upstroke*, a *downstroke*, a *forward movement*, a *rearward movement*, and a *partial rotation* of each wing on its long axis.

It was formerly supposed that the torsion of the wings, including the horizontal and rotary movements, is entirely the result of air pressure on the wings as they are vibrated in a vertical direction. This idea was elaborated

particularly by Marey (1874). There is no doubt that the wings do respond by a differential action in their planes to air pressure alone. It has been shown by Bull (1904a) that the wing of a dragon fly attached to a vibratory apparatus in a vacuum jar takes on the rotary movement automatically when air is admitted. Later, however, Bull (1910) observed that the stump from which a wing has been severed in a living insect is deflected forward with the downstroke and takes a reverse position during the upstroke. It is now conceded by students of the insect wing mechanism that the movements of the wing, though in part automatically possible by air pressure, are all produced, or at least augmented, by the action of the wing muscles. Directive movements of the wings, it must be observed, are only possible through muscular and nervous control.

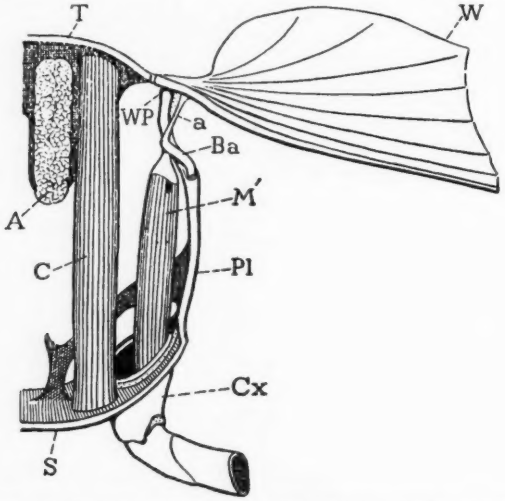

FIG. 20.—Diagram of the "direct" and "indirect" wing muscles in left half of a segment, anterior view. *A*, Section of longitudinal dorsal muscle ("indirect" depressor of the wings); *a*, membranous connection of basalare (*Ba*) with base of wing; *Ba*, basalare; *C*, tergo-sternal muscle ("indirect" elevator of the wing); *Cx* coxa; *M′*, coxo-basalar muscle ("direct" pronator-extensor of the wing); *Pl*, pleuron; *S*, sternum; *T*, tergum; *W*, wing; *WP*, pleural wing process.

The upstroke of the wing, as we have seen, is produced by the simple device of depressing the back plate, or tergum, of the segment bearing the wings (Fig. 17 A), the action being the result of a contraction of the vertical, tergo-sternal muscles (Figs. 17 A, 20, *C*). The mechanism of the upstroke, therefore, is that of a lever of the first class, the fulcrum being the pleural wing process (*WP*) upon which the base of the wing rests. The tergo-sternal muscles are often large and powerful, suggesting that the upstroke of the wings is an important contributant to the force of flight.

The downstroke of the wings is not the work of a single set of muscles. It results in part from the restoration of the dorsal curvature of the back by the contraction of the dorsal longitudinal muscles (Fig. 17 C, 20, *A*; Fig. 18—81, 112), which are the segmental antagonists of the tergo-sternal muscles; but probably an important effector of the wing depression in most insects is the posterior pleural muscle (Figs. 13, 19, *M″*) inserted on the subalar sclerite (*Sa*). The subalar sclerite, as we have seen, is in immediate connection with the second

axillary of the wing base (*2Ax*), and a pull upon the subalar muscle strongly depresses the wing.

The forward and rearward movements of the wing during flight are of small extent, but of much importance. They evidently are produced by the anterior and posterior pleural muscles (Figs. 13, 19, *E*, *M'*, and *M''*) pulling on the wing base, respectively before and behind the pleural fulcrum (*WP*).

The rotation of the wing on its long axis accompanies the anterior and posterior movements, and is produced by the same muscles, namely, the muscles of the basalar and subalar sclerites. The first (Fig. 20, *M'*) pulling downward on the basalare (*Ba*) turns this sclerite inward on the upper edge of the pleuron (*Pl*), and the connection (*a*) of the basalare with the humeral angle of the wing base deflects the anterior part of the wing as it turns it slightly forward. The mechanism of deflection, including the basalar sclerite and its muscle, has been called the *pronator apparatus* of the wing. The movement of pronation accompanies the depression of the wing. (Fig. 17 C.) The reverse movement, or the deflection of the posterior part of the wing accompanying the upstroke (Fig. 17 C), is probably caused mostly by air pressure on the expanded, flexible posterior area of the wing surface, but it is likely that the tension of the posterior pleural muscle (Figs. 13, 19, *M''*), pulling on the second axillary sclerite posterior to the fulcrum, contributes to the posterior deflection of the wing during the upstroke.

The motion of each wing in flight is, then, the resultant of its several elemental movements. During the downstroke the wing goes from above downward and forward; its anterior margin is deflected and its posterior area turns upward. (Fig. 17 C.) During the upstroke, the wing goes upward and backward, and its posterior surface is deflected (A).

By comparing the movements of an insect's wings in motion with the action of the blades of an aeroplane propeller, it will be seen that there is a similarity between the two. The planes of the propeller blades are so turned that each blade in rotating to the right cuts downward through the air with a forward slant, while on the left it goes upward with a rearward slant. The edge of the blade that opposes the air, moreover, is bevelled in such a manner that it lies in the plane of rotation. The insect wing differs from the propeller blade in that, by its flexibility, it can successively adapt the different parts of its surface to the same changes in relative position during an up-and-down movement that the rigid propeller blade assumes in revolution. The mechanical effect produced by the two instruments is the same, as we shall see in the next section of this paper.

As a result of the compound movements of the vibrating insect wing, the tip of the wing, if the insect is held stationary, describes a curve having the form of a figure 8. This fact has long been known; it was first demonstrated visibly by Marey (1860, 1874) who attached bits of gold leaf to the wing tips of a wasp and observed the luminous figures described when a beam of strong light was thrown on the vibrating wings. The movements of the wings have since been studied more accurately, however, by mechanical devices in which the vibrating tips are allowed to touch lightly the surface of a moving sheet of smoked paper, thus inscribing a record of their movements which can be more carefully examined. The most successful studies of this kind are those of Ritter (1911) who constructed an apparatus that would rapidly slide a small board covered with blackened paper past a blowfly secured in such a position that the tip of a vibrating wing would record its motions on the paper. Fig. 21 shows two of the curves obtained by Ritter with this apparatus when the head of the fly was directed opposite the movement of the sliding board. The lines of these tracings, therefore, may be taken to show the track described by the wing tips in normal forward flight. Instead of making a figure 8, the wings of a fly in motion describe a series of open loops in which the downstroke takes the form of an italic curve inclined from

above downward and forward, while the reverse stroke goes from below upward and posteriorly. The distance between the loops will depend on the speed at which the insect flies. The rotary movement of the wings is most accentuated in swift-flying insects, such as the dragon flies, bees, and flies, which have relatively narrow wings; in slower-flying insects with broad wings, such as the grasshoppers and butterflies, the up-and-down movement is the principal one.

That the movements of animals, including the flight of insects, could be studied from series of moving-picture photographs was first demonstrated by Marey (1901). With more improved methods, von Lendenfeld (1903), Bull (1904), and Voss (1914) have obtained cinematographic records giving a convincing demonstration of the nature of the insect wing movements in flight. Voss made calculations from his serial pictures of the number of wing strokes a second in many species of insects. However, much of interest might yet be done by this method of research.

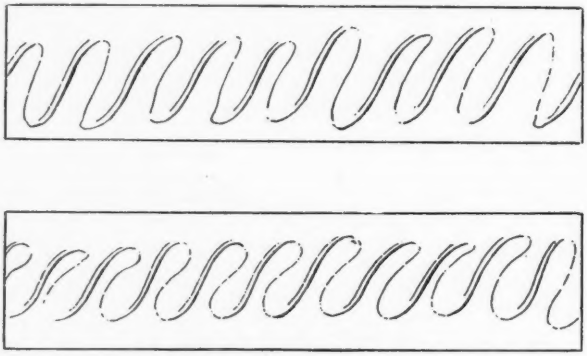

FIG. 21.—Curves described by the tip of a blowfly's wing in flight. Tracings made by the tip of the wing of a fly held stationary with the head directed toward the movement of the recording surface. (From Ritter, 1911).

The rapidity of the wing movements varies greatly in different insects. The first statements concerning the rate of vibration of insect wings are those of Landois (1867) deduced from observations on the pitch of the sound made by insects in flight. Landois thus estimated that the house fly makes 352 wing strokes a second, a bumble bee 220, and the honey bee 440 when at its best, though when tired its hum indicates a wing speed of only 330 beats a second. By the same test, the mosquito, it is said, must make as high as 600 wing beats a second. The wing movements have been studied also with mechanical apparatus and from serial photographs. The records of different investigators differ considerably, but it must be recognised that experimental results give at best only the rate at which the insect moved its wings under the conditions of the experiment; it is well known that most insects can vary the speed of their normal flight within wide limits. Marey (1869a) obtained graphic records of the wing beats on a revolving cylinder, and he gives 330 wing strokes a second for the house fly, 240 for a bumble bee, 190 for the honey bee, 110 for a wasp, 28 for a dragon fly, and 9 for the cabbage butterfly. Voss (1914), however, calculating the rate of the wing motion from series of moving-picture photographs, obtained in most cases lower figures; the honey bee, by his test, making 180 to 203 wing strokes a second, the house fly from 180 to 197, the mosquito from 278 to 307, while various other insects have mostly a slower rate. In general, it may be said, the flies and bees have the highest rate of wing movement; most other insects, by

comparison, being slow of flight and correspondingly slow in wing motion. The lowest records of wing speed are found among the butterflies and moths, the cabbage butterfly making at best about 9 strokes a second, and some of the noctuid moths about 40; the sphinx moths, on the other hand, are swift flyers and move the wings at a high rate of speed. The reader may find summarised statements on the recorded rates of the wing strokes in insects given by Voss (1914) and by Prochnow (1921-1924).

The movements of flexion and extension.—The movements by which the wings are folded after flight, or extended preliminary to flight, are executed too rapidly to be observed closely in a living insect; but the action of a wing and the operation of the flexor mechanism can be well studied in freshly-killed specimens. A grasshopper, a bee, a fly, or most any insect sufficiently large will answer the purpose, but the grasshopper, or particularly the scorpion fly, *Panorpa*, will be found to be a very suitable subject. If the wing of a fresh specimen is slowly folded posteriorly over the back and then brought forward into the position of flight, the accompanying movements of the articular sclerites on one another can be observed, and from their action the probable working of the flexor mechanism in the living insect can be deduced.

First we must look again at the plan of the general wing structure. (Figs. 14, 22 A.) The region of the articular sclerites, or axillaries, forms a triangle at the base of the wing (*Ax*) with its apex (*c*) supporting the base of the vannal region (*V*). When the distal parts of the wing are well differentiated, the vannus is usually separated from the remigium (*Rm*) by a vannal fold, or plica (*vf*), and the jugal lobe (*Ju*) is separated from the vannus by a jugal plica (*jf*). The axillary sclerites are highly variable in form in different insects, but their relationships to one another and to the bases of the veins are constant. The articulation of the radial vein (Fig. 12, *R*) with the second axillary (*2Ax*) lies at the point *d* on the anterior side of the axillary triangle (Fig. 22 A). The edge of the triangle between this point and the apex (*c*) is formed by the line of flexion, or *plica basalis* (*bf*), between the median plates of the wing base (Fig. 12, *m*, *m'*), or between the corresponding areas if the plates are obsolete or absent. The third axillary sclerite (Fig. 12, *3Ax*) is the crucial piece of the flexor mechanism. Typically it is essentially Y-shaped, the two prongs being the arms of the mesal part hinged by their tips (*f*, *b*) between the second axillary and a posterior process of the tergum, with the flexor muscle (*D*) inserted in the crotch, while the stalk is the distal arm, the end of which is closely associated with the bases of the vannal veins (*1V*, *2V*) at the apex of the axillary triangle (Fig. 22 A, *c*.)

When the muscles that keep the wing extended are relaxed, the wing automatically turns a little posteriorly, and a prominent convex fold is formed along the oblique plica basalis (Fig. 12, *bf*) at the base of the medio-cubital field of the wing, which is between the two median plates (*m*, *m'*) when these plates are present. At the same time, the third axillary sclerite (*3Ax*) is revolved upward on its basal hinge, or hinges (*b*, *f*), until the insertion point of its muscle (*D*) lies dorsal and slightly mesad to the axis of the hinge. The muscle, which arises on the inner wall of the pleuron below the wing base (Fig. 19, *D*), thus acquires an effective purchase on the third axillary, and, by contraction, it evidently now continues the revolution of the sclerite, turning the outer end of the latter (Fig. 12, *c*) dorsally, mesally, and forward, until the sclerite is completely inverted and reversed in position. Concomitant with the movement of the third axillary, the first median plate (*m*), which is usually attached to the latter, turns to a vertical position between its hinge with the second axillary (*2Ax*) and its hinge with the second median plate (*m'*), or with the base of the medio-cubital area of the wing, and this line of flexion (*bf*) is swung inward posteriorly until it takes an oblique position extending from in front posteriorly and mesally, overlapping the posterior part of the second axillary.

The movements of the third axillary and the attached median plate (*m*), caused by the contraction of the flexor muscle (*D*), bring about the flexion of the wing and, incidentally, whatever folding the wing surface undergoes during flexion. The mesal revolution of the third axillary directly lifts the base of the

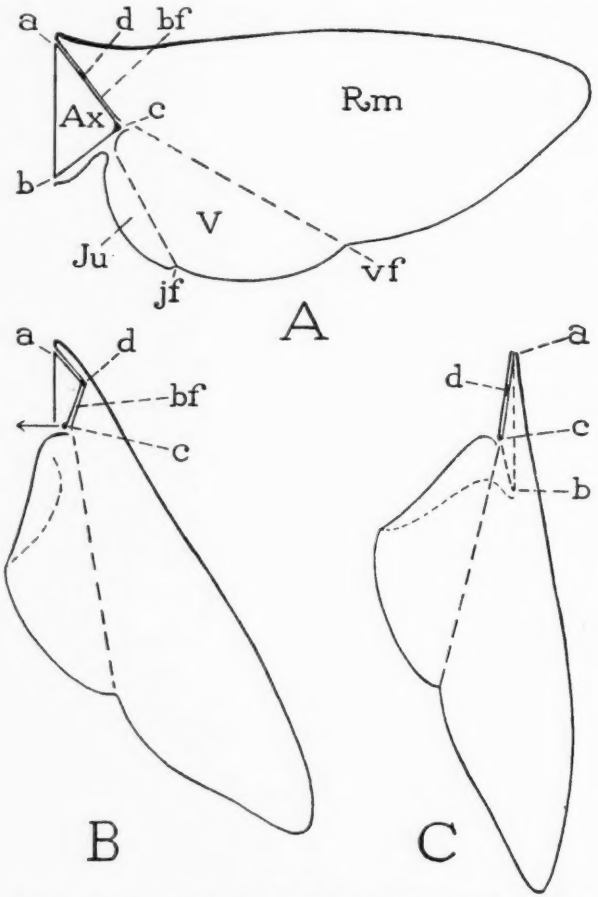

FIG. 22.—Diagrams illustrating the flexion of a wing. A, The extended wing, showing folds and regions named on Fig. 14; B, the partly flexed wing, showing the basal folding along the plica basalis (*bf*), and the jugal region lapped beneath the vannu along the jugal fold; C, a fully flexed wing in which the entire axillary region is turned vertically on its base (*a–b*); the vannus is elevated by the apex (*c*) of the axillary region and turned horizontally against the body; the remigium, turned posteriorly on the point *d* (see Fig. 12), slopes downward and laterally on the flexure at the vannal fold.

vannal region of the wing associated with the end of its distal arm, and brings it to a mesal position against the side of the body. At the same time, the upward revolution of the first median plate (*m*) on the second axillary (*2Ax*), and the consequent inward swing of the posterior end of the plica basalis (*bf*)

between the two median plates (*m*, *m'*) turns both the medio-cubital and vannal areas of the wing posteriorly. The costo-radial area necessarily follows, turning posteriorly on the hinge of the radius (*d*) with the second axillary, and on that of the subcosta (*e*) with the first axillary. As the posterior edge of the wing comes against the side of the body, the jugal lobe (*Ju*) is deflected and turned beneath the vannus along the line of the jugal plica (*jf*). If a vannal plica (*vf*) is present, the remigial region is usually turned downward during the flexion of the wing; but many insects, such as the flies and bees, keep both the remigium and the vannus in a horizontal plane.

The final pull of the flexor muscle is apparently expended on the general wing base, for, in many insects, when the wing is fully flexed, the second axillary is turned into a nearly longitudinal position and is brought close to the side of the back by a vertical revolution of the first axillary on its hinge with the tergum. Thus, in the typical, fully-flexed condition of the wing, the first axillary (Fig. 12, 1*Ax*) stands in a vertical plane of the edge of the tergum; the second axillary (2*Ax*), supported by the first, lies horizontally close to the body; the first median plate (*m*) either stands vertically from the outer edge of the second axillary, or it is inclined mesally and overlaps the latter; the second median plate (*m'*), or the base of the medio-cubital wing area, lies horizontally but makes a sharp fold along the hinge line (*bf*) with the first median plate, the fold crossing the wing base obliquely from the base of the radial vein posteriorly and medially; the third axillary is completely inverted with its apex (*c*) directed mesally and forward. Flexion of the wing does not alter the position of the first and second axillaries in some insects; but the revolution of the third axillary is invariable, showing that it is the motion produced in this sclerite by its muscle, and the consequent folding in the parts immediately affected by its movements that bring about the rotation of the distal parts of the wing on the basal elements, which constitutes flexion.

The automatic nature of the complicated movements of the wing folding, resulting from the pull of a single muscle, may be roughly demonstrated with a piece of stiff paper cut and creased along the lines of Fig. 22A, but leaving an extension to the left for support. Lifting the apex (*c*) of the axillary triangle, and revolving it on the base (*a*—*b*) to the left (*B*), will turn the vannal region of the model (*V*) posteriorly and deflex the remigial part (*Rm*). If the apex (*c*) is finally turned mesad of the base line (*C*), the distal parts of the paper model will take positions quite comparable with those of the parts in a wing of similar form flexed and folded by the revolution of the third axillary sclerite. The details of interaction between the sclerites of the axillary region, and the folding of the latter upon itself, cannot, of course, be duplicated unless the entire mechanism is reproduced. A well-constructed model of the base of an insect's wing, made on a large scale, would enable us to understand more accurately the working of the flexor mechanism, and, incidentally, it should be an excellent object for museum display.

The flexing of the wing becomes a still more complicated process if the vannal region is particularly enlarged. In some of the Orthoptera, including most of the cockroaches, the grasshoppers, and the crickets, and in some other insects, the vannus of each hind wing is so much expanded (Fig. 15 B) that, when the wing is flexed, it must be plaited and folded up like a fan (Fig. 23 B) in order to give space for the rest of the wing. In wings that are plaited during flexion there may be, as in the hind wing of a grasshopper, two lines of folding between the remigium and the vannus with a dividing vein, or *vena dividens*, between them. (Fig. 15 B, *Vd.*) The folding and plaiting of the fully-flexed wings of a grasshopper are shown in Fig. 23. The narrower forewings, or *tegmina* (A, W_2), overlap each other to form a roof-like covering with steeply sloping sides completely inclosing and protecting the more delicate hind wings (W_3) folded beneath them.

The extension of the wing involves a reversal of the movements of flexion. The flexor muscle must first relax. A contraction then of the anterior pleural muscles (Figs. 13, 19, *E*, *M'*), pulling on the humeral angle of the wing base, may extend the wing directly, though the action of these muscles in this capacity is often difficult to demonstrate in a dead specimen. With insects in which the second axillary sclerite is elevated on the outer edge of the first axillary in the fully-flexed wing, it is clear that the wing may be extended by the downward pull of the posterior pleural muscle (*M'*) on the second axillary, for a pressure on this sclerite at once restores all the axillary elements to a horizontal plane and thereby spreads the wing. Some insects may be seen to extend the wings deliberately before taking flight, but with most species flight is practically simultaneous with the wing expansion.

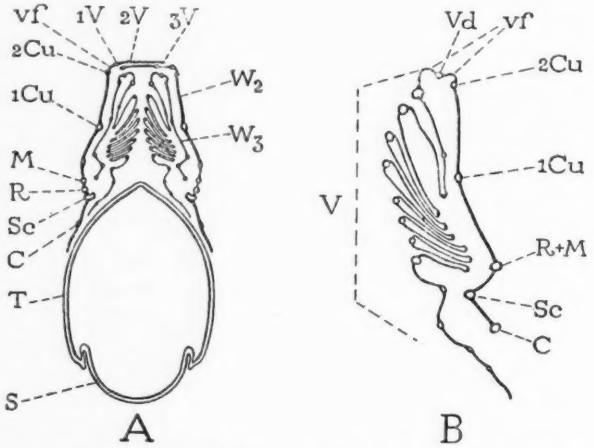

FIG. 23.—Cross sections through the folded wings of a grasshopper (*Dissosteira*). A, Cross section through the wings and the abdomen; the forewings, or tegmina (W_2), when closed, form a compartment over the back (*T*) in which are folded the large hind wings (W_3); B, cross section of the right hind wing, posterior view, showing the many plaits of the vannal region (*V*) which is folded like a fan. Lettering as on Fig. 15.

7. Flight

Flight by any heavier-than-air machine or animal that does not depend on currents or rising columns of air requires a mechanism capable not only of producing a forward motion, but also of creating a lifting force sufficient to overcome the pull of gravity. Soaring birds and gliding planes keep themselves aloft after the manner of a kite; the extent of their area that they oppose to the air sustains them on the air pressure created beneath. The ordinary aeroplane is driven only forward by the direct action of its airscrew; it is lifted by the areas of decreased pressure created above its slanting wings by the force of its forward motion. With most insects the area of the wings is far too small, in proportion to the size and weight of the insect's body, to have much value as a planing surface, and, moreover, the wings are the active elements in the motor mechanism. A small-winged insect, therefore, can neither soar in the manner of larger birds, nor can it sustain itself in the way the moving aeroplane does. The wings of insects must furnish not only the driving power, but a lifting force as well, which is to say, the movement of the wings must create a region of lowered pressure both before and above the body of the insect.

An interesting and instructive study of the effect of the wing movements of insects on the surrounding air has been made by Demoll (1918). By means of a simple apparatus consisting of a frame with several horizontal cross bars on which were suspended rows of fine owl feathers, Demoll was able to demonstrate the direction of the air currents created by the wings in vibration when the

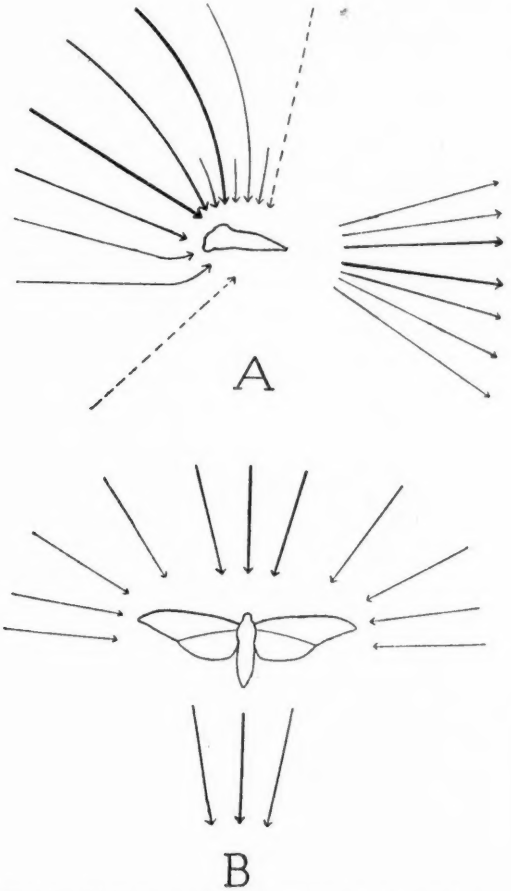

FIG. 24.—Diagrams showing the currents of air created by the vibrating wings of an insect held stationary. The thickness of the arrows indicates the relative strength of the currents. (From Demoll, 1918.) A, Lateral view, showing currents in the median vertical plane; B, dorsal view, showing currents in the horizontal plane.

insect itself is held stationary. The lightness of the feathers made the latter delicately responsive to any disturbance of the air in their immediate vicinity, and thus the air currents set up by the whirring wings of an insect, secured by the body in such manner that the wing movements would not be hindered, were registered in the displacement of the feathers. Experimenting in this way with insects of different orders, Demoll found that the currents of air drawn toward

a stationary insect by the vibrations of its wings come not only from in front, but also from above, from the sides, and from below, and that the currents given off are all thrown out to the rearward. (Fig. 24.) The strength of the currents, however, is not the same from all directions, as is indicated by the relative thickness of the arrows in the diagrams. The air is drawn toward the insect most strongly from before and above the anterior part of the body; the outgoing currents are strongest in a horizontal or slightly downward direction. Most of the oncoming currents, therefore, are turned to the rear in the neighbourhood of the insect's body, and condensed in a small region behind it.

If the insect is free to move, the mechanical effect of the vibrating wings on the air will be the same as when the insect is held stationary; but, instead of moving the air, or instead or moving the air to the same extent as before, the greater part of the wing force will propel the insect through the air opposite the direction of the air currents created when the insect is secured. The fact that the vibrating wings produce air currents does not mean that the insect will be carried along on the currents of its own production; in terms of mechanics, as we have seen, the direction from which a current of air is drawn by a stationary object is the direction of lowered pressure, while the opposite is that of increased pressure. According to the observations of Demoll, therefore, when an insect launches itself into the air and starts the vibration of its wings, there is at once created before it and above it a region of decreased pressure, and the convergence of all the currents behind produces here a region of greatly increased pressure. The lowered pressure above counteracts the weight of the insect; the increased pressure behind drives the insect forward into the low-pressure region in front. Thus, Demoll points out, while the soaring bird, with large outstretched wings practically stationary, rests upon the air, the flying insect, with small but rapidly-moving wings, is suspended in the air. The bird, a glider plane or a kite, is borne up by increase of pressure below; the insect, on the other hand, is sucked up into the air and held suspended by the partial vacuum that its wings create above it. The flying mechanism of the insect, therefore, is comparable with that of a helicopter aeroplane, except that in the insect the wings neatly combine the function of two sets of propellers working at right-angles to each other. If both propellers of a bi-motored aeroplane were directed forward and upward, the machine would resemble an insect—if it could fly. The body weight of an insect is so distributed that the centre of gravity lies behind the wing bases, usually at the base of the abdomen. (See Demoll, 1918.)

The driving force of the insect's wing movements probably depends upon the angle at which the wing surfaces cut the air. Slow-flying insects with broad wings, such as the butterflies and grasshoppers, keep the wing surfaces almost horizontal and fly more in the manner of small birds with comparatively few strokes of the wings in any unit of time. Some of the large swallowtail butterflies even soar for short distances with the wings held stationary. The more swiftly-flying insects, however, having narrow wings, turn the wing surfaces more nearly vertical with each stroke, whether up or down, but as Ritter (1911) says, "the insect flies fastest when the downstroke approaches a vertical direction," because the greater the speed the more the curve of the upstroke is drawn forward in the direction of flight.

The speed of insect flight may be very high, considering the small size of insects. Demoll (1918) gives a table of the rate at which different species fly, obtained by setting individuals at liberty in a room lighted by one window and recording the time in which they flew direct from the dark side of the room to the light. Among the swiftest flying insects, according to this test, are the hawk moths (Sphingidæ), a horsefly (*Tabanus bovinus*), and the dragon flies. The hawk moths made a speed up to 15 metres a second, followed closely by *Tabanus bovinus* going at a rate of 14 metres. A dragon fly (*Libellula depressa*), doing ordinarily 4 metres a second, can make 6 to 10 metres in the same time when

flying rapidly. A house fly travels from 2 to 2.3 metres a second; a bumble bee (*Bombus*) from 3 to 5. The honey bee, Demoll says, when flying unladen from the hive, has a speed of 3.7 metres a second, but on the return, if loaded with pollen, its speed is cut down to 2.5 metres for the same unit of time. The pollen load of the bee, according to Demoll, weighs about 20 milligrams, which is approximately 30 per cent. of the body weight of the bee.

The ability merely to progress through the air is not efficient flight. The smaller grasshoppers leap into the air and sustain themselves for some distance by movements of the wings, but they have small power of directing their course after they leave the ground. Some of the migratory locusts ascend to great heights and go long distances on the wing, but they are probably dependent largely on the wind for transportation. The Carolina locust is a better flyer, but its course on the wing, though more or less directive, appears to be rather haphazard. Real flight involves the ability to steer a definite course, and to turn this way or that as exigencies demand. By this test the majority of insects are expert flyers, and we need only observe a dragon fly foraging for smaller insects over the water, one of the smaller horseflies dodging the ineffectual counter strokes of its intended victim, or a hawk moth poised in the air as it extracts the nectar from the depths of a corolla, to realise how adroitly insects can make use of their wings in controlling their flight.

Insects are not provided with rudders. There is little evidence that they use their bodies or their legs to direct or alter their course while in the air. Stellwaag (1916), who has made a special study of the steering powers of insects, points out that if directive flight were accomplished by movements of the legs or the abdomen, these movements could be detected in the more slowly flying species, whereas, in fact, no such movements are either visible by close inspection or can be detected by mechanical devices. Shadowgraphs of flying insects, he says, record no alteration in the position of the body or of the legs during a change in the direction of flight. Observations on insects held in a pair of tweezers and turned at various angles also failed to show compensatory movements in the body or appendages. Finally, Stellwaag resorted to experimentation on living insects impaled on slender pins thrust vertically through the thorax. Insects thus secured vibrate the wings as in flight and revolve to the right or the left on the axis of the pin, whether the latter is held vertical or inclined, but the turning is never accompanied by movements of the legs or abdomen. Steering, therefore, Stellwaag concludes, is evidently accomplished by a differential action in the wings themselves.

With the insects held on pins, it is possible to observe the action of the wings directly; and to make the wing movements more evident Stellwaag employed the method used by Marey of attaching bits of gold leaf to the wing tips and throwing a strong light on them while in motion. In many cases, he says, not only the plane of the wings is seen to be altered as the insect revolves itself on the pin, but there is also visible a change in the amplitude of the wing strokes on one side or the other. From these experiments it is evident that the flying insect must control the direction of its flight after the manner of a rower in a boat, who, in the absence of a helmsman, keeps to his course, or alters it, by changes in the manipulation of the oars.

The muscles of the insect concerned in the differential action of the wings must be the pleural muscles of the alar segments, which are those of the basalar and subalar sclerites (Fig. 19, *E*, *M'*, and *M''*), since these muscles alone have specific connections with the wings. The longitudinal and vertical muscles of the wing-bearing segments, though potent effectors of wing movements, cannot unequally distribute their influence between the two sides of a segment.

It is not surprising that insects should be experts on the wing, considering that they have been flying for several hundred million years, but still we are inclined to marvel when we see them perform feats that are as yet quite impossible

for our newly-developed heavier-than-air flying machines. In addition to their ability to steer themselves adroitly in forward flight, many insects can go into reverse gear and fly directly backward without altering the position of their bodies, and, moreover, they have also some mechanism of adjustment by which they can fly sidewise, either to the right or left, at right angles to the body axis. The dragon flies are particularly adept in these modes of flight, but many of the smaller insects, such as the flies and bees, are quite equal to the dragon flies in being able to dart suddenly to the side or rearward while the head still points in the direction of the arrested forward flight. Reversed and lateral flying is probably controlled also by the pleural muscles of the flight mechanism, which alone can give an altered or differential action to the wings; but it is remarkable that organs so evidently fashioned for forward flight, as are the wings of insects, can function efficiently for producing motion in other directions.

Still another feat that many insects perform on the wing with seeming ease is *hovering*. Keeping the wings in rapid movement, the insect remains without other motion suspended at one point in the air, even maintaining its position in the face of a slight breeze. Presumably, in hovering, the wings are vibrated

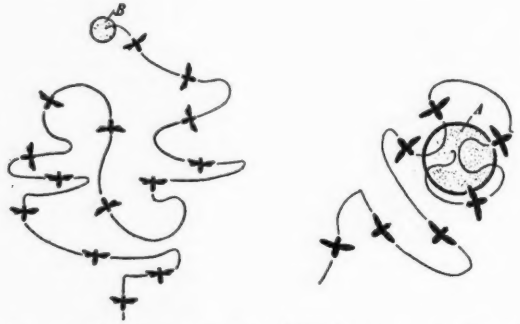

FIG. 25.—The course taken by a honeybee (*A*) and a drone fly (*B*) approaching a flower. (From Stellwaag, 1916.)

approximately in a horizontal plane, thus creating a region of decreased air pressure above the body but not before it. The rate of the wing movements then must be just sufficient to create a balance with the pull of gravity. A drift on air currents must be counteracted by compensatory changes in the angle of the wing vibrations.

An interesting illustration showing the course taken by a honey bee or by a drone fly approaching a group of flowers is given by Stellwaag. (Fig. 25.) The insect arrives head on, arrests its flight and swings to the right or left still headed toward the flowers; next, it circles about in ordinary forward flight, making a closer approach; now, perhaps, it hovers, again zig-zags sideways, and finally goes direct to a particular blossom.

Considering how adept are insects on the wing, it seems certain that they must have a highly developed " sense " of equilibrium. And yet, among the numerous and diverse sense organs with which insects are known to be equipped, organs to which might be assigned a static function, or the control of balance, have been found in very few cases, and principally in certain small forms (Phylloxera) with limited powers of flight. Lacking evidence of the existence of organs of equilibrium generally distributed in insects, we might suppose that the maintenance of balance during flight is an automatic reaction through the sense of sight. The writer has found, however, that a large swallowtail butterfly (*Papilio polyxenes*) is able to fly well after having its eyes thoroughly blackened

with a mixture of glue and powdered charcoal until it no longer reacts to light in a room. (The normal butterfly goes at once to a window.) An individual thus blindfolded fluttered about aimlessly in a room with three windows on one side, though before, when liberated, it flew directly to a window. Taken out of doors it immediately flew upward in widening circles, finally going high over the roof of a two-storey house and disappearing over the tops of trees beyond. Clearly this insect did not require the use of its eyes to keep itself in the proper position for flying. Another individual of the same species was able to fly in the normal way when its entire head was cut off, though, after the manner of insects lacking a brain, it had no inclination to do so, except when artificially stimulated. When thrown into the air it fell straight down, but the sudden contact with the ground stimulated it to make a short flight, during which it was well able to keep its balance. When at rest, it held the wings folded above the back in the usual fashion, though the body tilted somewhat to one side, a result of the loss of " tonus " in the muscles always shown by decerebrated insects.

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THE MANUFACTURE AND USE OF LIGHT ALLOYS

BY

W. C. DEVEREUX

(Lecture read before the Coventry Branch, November 30th, 1932.)

At quite short notice I was asked to deliver this paper and told at the same time that I must make it popular and not adhere too much to technicalities. This makes it very difficult for me. It would have been more simple if I had been allowed to keep to technicalities and state facts on the development and manu-

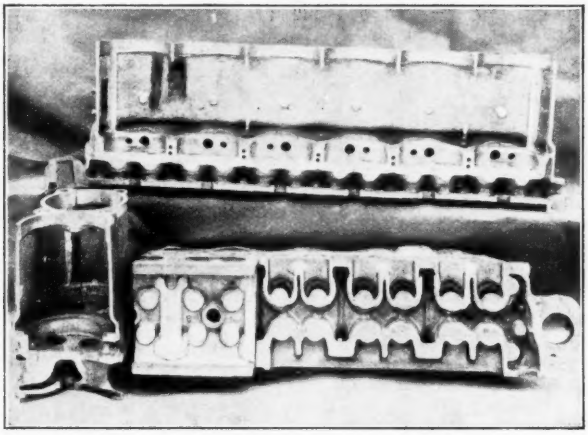


FIG. 1.

Rolls-Royce cylinder block section.

facture of the aluminium alloys. One of the advantages of being associated with a metal as relatively new as aluminium is that one never has a dull moment; a metal which, in a short ten years or so, increases in demand by some 300 per cent., not only creates an atmosphere of power and progress, but imposes on one problems to be elucidated by chemists and metallurgists, and calls certainly for specialising, and the specialities of my works are in the manufacture and application of those aluminium alloys which gain their high strength by suitable forms of heat treatment. Our main business has been to satisfy the demands of the designer of aircraft and aircraft engines, who is influenced by two major considerations, reliability and weight. The need for reliability is readily appreciated and the necessity for weight saving is universally recognised.

In considering an automobile and an aircraft, weight for weight, the aeroplane will usually be equipped with an engine developing eight or nine times more horse-power, and will then have a carrying capacity of less than that of the automobile; it is obvious that each pound eliminated from the structure means an additional pound carrying load. It is quite easy, therefore, to understand the

limitations imposed upon the aircraft designer and to appreciate his insistent demands for light, strong and enduring structural material. The factor of safety is necessarily of the finest, and the inspection of materials must be of a high degree. Consistency in manufacture must be ensured. Materials must be such that, while giving good test piece figures the parts must be consistent and sound throughout, and uniform in their properties.

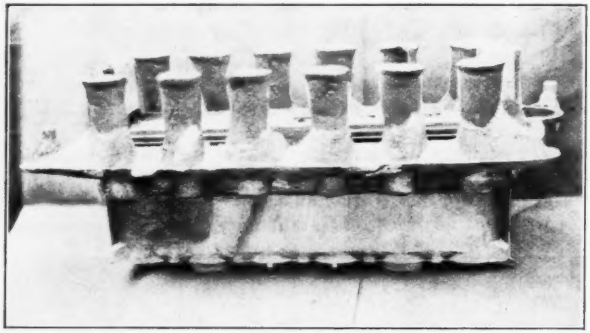


FIG. 2.
Rolls-Royce cylinder block.

I propose, therefore, in addition to giving particulars of various aluminium alloys used in aircraft and engine construction, to show what endeavour is used to attain soundness and reliability.

To take first water-cooled engines for aviation, the general principles do not differ widely in design from standard water-cooled engine practice. The application of aluminium alloys to the former, however, is carried beyond the generally

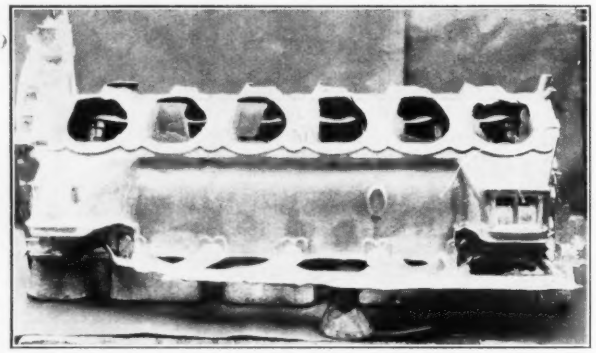


FIG. 3.
Rolls-Royce crankcase, R.R.50.

accepted standard for other types of service. Difficulties attendant in providing water jacket coring in a cylinder block and cylinder head, and the general design of crankcase make it essential to rely upon casting. Fig. 1 shows a section view of the Rolls-Royce engine cylinder block; this is made in "Hiduminium" R.R.50, and has a general thickness of .175; the water jacket is tested in air at

80lbs. per sq. inch pressure under hot water, and the combustion chamber at 360lbs. per sq. inch. Fig. 2 shows the same cylinder block and head, showing the method of feeding. With " Hiduminium " R.R.50 material very few chills are used, as demonstrated in the previous picture. Chills make difficulties for the designer, since, wherever chills are used there is a certain indefiniteness about the form and the thickness of each casting. The abrupt change of structure between the chilled and the unchilled portion of a casting is not at all a desirable feature and tends to properties in the part which are not uniform. With the " Hiduminium " R.R.50 material one has a very short range of solidification, a desirable feature providing ample feeding is supplied in order to minimise the stresses of contraction upon solidification. The material has a low linear casting contraction, namely, .125 per ft. as against .15 for 2L.5 and .188 for the 4 per cent. Cu. American alloy—I mention these alloys as they are two with which you will be familiar. This low linear casting contraction you will readily see causes very little stress upon contraction on to the cores, so little in fact that in the cylinder block shown no attempt is made to strip the mould or cores while the castings are hot.

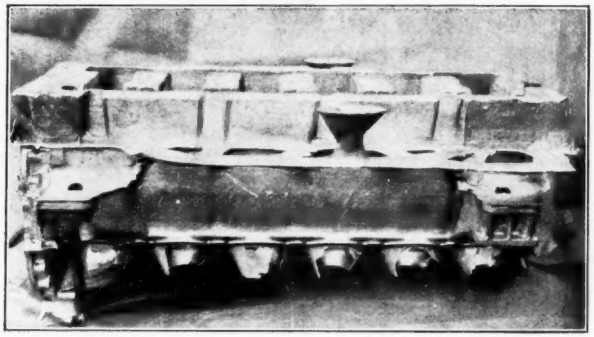


FIG. 4.
Rolls-Royce crankcase.

Fig. 3 shows the Rolls-Royce crankcase casting which is made entirely without chills. This casting is really a beautiful demonstration of design made suitable for the use of the peculiar properties of the material. Fig. 4 is another view which more readily shows the methods of running and rising. This casting likewise has a general thickness of only .175in. The supercharger casting shown in Fig. 5 is also made entirely without chills, and has a general thickness of only .125in., while Fig. 6 shows another type of supercharger where only six chills are used actually at the heavy sections; Fig. 7, giving another view of the same part, shows where the remaining chills are fitted; this casting is likewise .175 in the body, with webs .125in. thick, and is tested by air under hot water at 120lbs. per sq. inch pressure.

I do not intend to refer at length to the figures regarding physical properties; these can all be obtained from the various publications and literature. The main points, as you will see, in the use of the material lie in the ease with which it can be cast, and the beauty of the finish, and the fact that if fed correctly the unsightly drawing between thin and thick sections is absent. A point I would also like to mention is that from the actual castings shown, test pieces have been taken which uniformly give a .1 per cent. proof stress of 8 tons per sq. inch; ultimate strength of 10 to 12 tons, and an elongation of 3 per cent., the Wohler fatigue value being 4.8 tons per sq. inch at 60 million reversals.

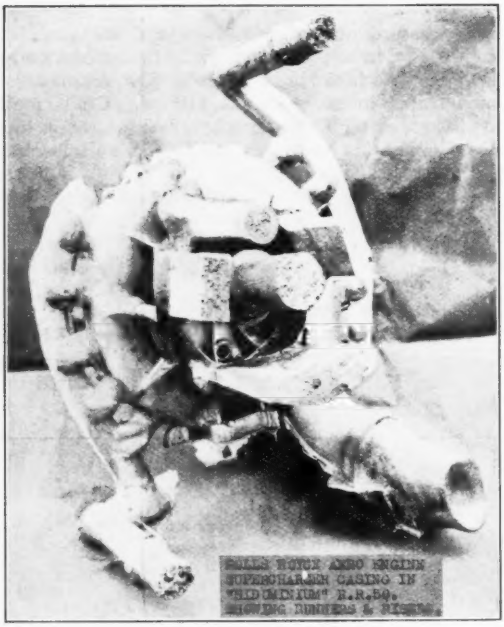

ROLLS ROYCE AERO ENGINE
SUPERCHARGER CASING IN
"HIDUMINIUM" R.R.50.
SHOWING RUNNERS & RISERS.

FIG. 5.

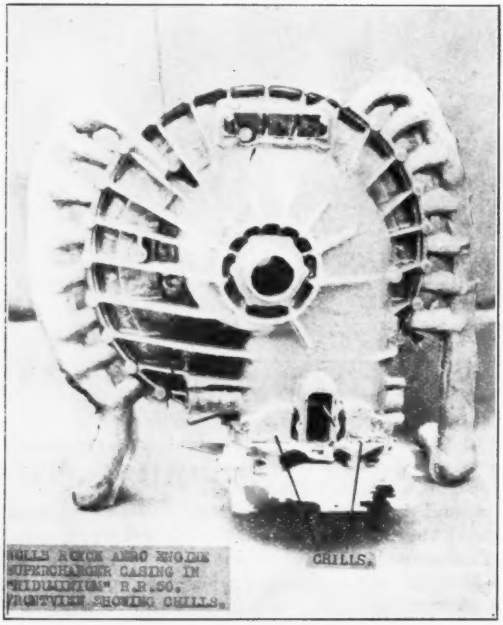

CHILLS.
ROLLS ROYCE AERO ENGINE
SUPERCHARGER CASING IN
"HIDUMINIUM" R.R.50.
FRONTVIEW SHOWING CHILLS.

FIG. 6.

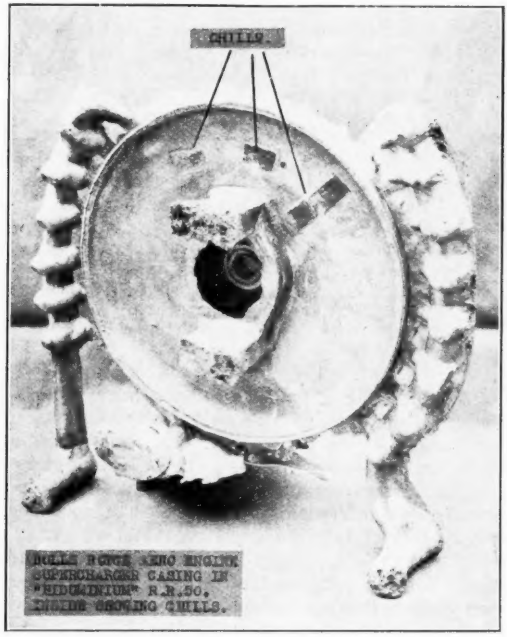


FIG. 7.

The aircraft designer is so essentially concerned that his castings should be consistent out of the mould that the following tests of hot shortness may be of interest to you. Fig. 8 shows the method; a tee-shaped pattern is placed in a

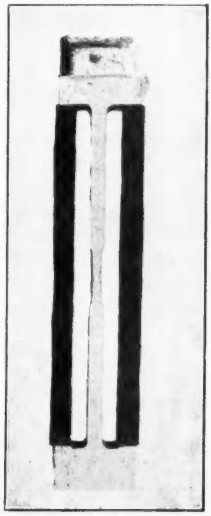


FIG. 8.

sand mould, allowing contraction on to two steel distance pieces. The test was commenced with distance pieces fitting the pattern, and subsequent tests done by machining clearances between the distance pieces and the pattern until all material remained unbroken—of course the clearance was filled in with sand. Table I gives the result of this test.

TABLE I.

HOT SHORTNESS TEST.

	Materials.							
Clearance	RR.50	DTD.25	RR.53E Special	3L11	RR.53	Y	2L5	American Alloy 4% cu.
Nil	Unbroken	Unbroken	Unbroken	Broken	Broken	Broken	Broken	Broken
21	,,	,,	,,	Unbroken	,,	,,	,,	,,
64								
23	,,	,,	,,	,,	Unbroken	Unbroken	Unbroken	Unbroken
64								

D.T.D.25 is a 13 per cent. sodium modified aluminium silicon alloy, but its low proof stress does not make it suitable for the parts shown or for stressed parts generally, while "Hiduminium" R.R.53E is a special alloy used in the manufacture of cylinder heads that are entirely die cast, whilst the standard R.R.53 may be used for sand cast cylinder heads. The "Hiduminium" R.R.53 alloy has since shown many applications for parts which are subjected to elevated temperatures commonly encountered in the hot spots of aero engines; this alloy was originally developed essentially as a piston material, either in the die cast or the sand cast condition. Weight is of primary importance in a piston, but of paramount importance for the judgment of a light piston alloy is running properties depending on high resistance to wear, high hardness in the hot condition and small dilatation; heat conductivity should naturally be taken with the latter.

Any metal is liable to seizing, but a metal having a low strength at high temperature will seize over a larger area than metal having a high strength in the heat. When seizing occurs and continues the plastic condition of the metal approaches the melting point and soon a hole will be burnt through. All metals are subject to this trouble, but that having a high strength at high temperatures is the most secure. Similar results arise when the lands are injured, which may occur even when the cylinder head is fitted or a sharp edge of some few thousandths of an inch in height may be produced by cylinder wear, causing the piston ring to strike against it; the ring is gradually destroyed and destroys the adjacent flange which in turn acts upon the next ring, and so on; in this way a large hole is produced through which the flow of the combustion gases burns the piston through.

In addition to avoiding these primary causes, high strength at temperature is the best prevention against such casualties, providing the material used is such, that in the casting, uniform properties throughout the mass are ensured. An occurrence often noted is the piston head burning through. This occurs when the cross-sections of the piston are not suitably dimensioned for the thermal transmission of heat or when the state of equilibrium in the heat flow is interfered with, again necessitating a material not only with a high heat conductivity but also with uniformity of structure and distribution of the elements.

Another fault in pistons, particularly those of the split skirt type, is that of the head portion breaking off at the weakest point, this point not being able to withstand the strain produced by the thermal and mechanical stresses in the cross-section concerned. This would be aggravated by overheating; notch effects due to faulty material; poor material due to faults such as piping, porosity; cracks due to hot contraction on uneven casting strains, and in some cases a fatigue at the weakest cross-section. The Brinell hardness was the almost exclusive criterion for the judgment of piston material for many years. This conception was placed on the idea that the sliding friction is less injurious to a surface the

harder the latter is. In view of recent research work it is almost entirely agreed that the Brinell hardness is not always a criterion in the determination of the wearing property of material. The Brinell hardness is defined by the degree of penetration of a hardened steel ball or diamond point into a material, the load of the ball being so chosen that permanent deformations are ensured at the point of contact. The resistance by the material to penetration, however, depends on the structure and not merely on the hardness of the various crystals; for example, crystals of the matrix may be very hard, while the texture is rather loose as, for instance, in the case of cast iron which contains many inclusions of graphite and gas, and so the ball will at first press the crystals into these hollowed spaces prior to encountering the resistance of the matrix proper; the Brinell press will thus indicate comparatively low hardness.

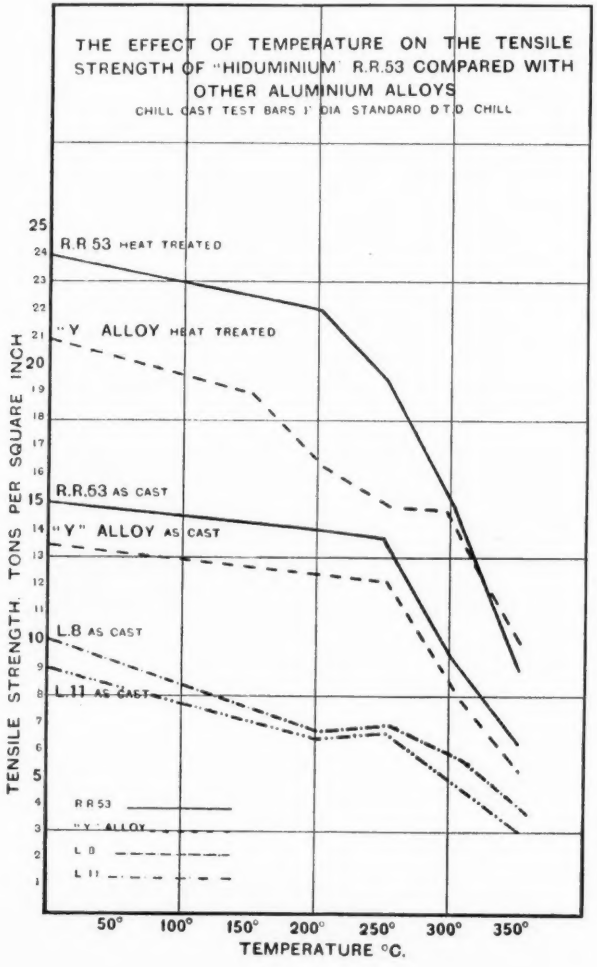

THE EFFECT OF TEMPERATURE ON THE TENSILE STRENGTH OF "HIDUMINIUM" R.R.53 COMPARED WITH OTHER ALUMINIUM ALLOYS
CHILL CAST TEST BARS 1" DIA STANDARD D.T.D CHILL
R.R 53 HEAT TREATED
"Y" ALLOY HEAT TREATED
R.R.53 AS CAST
"Y" ALLOY AS CAST
L.8 AS CAST
L.11 AS CAST
R.R.53
"Y" ALLOY
L.8
L.11
TENSILE STRENGTH. TONS PER SQUARE INCH
TEMPERATURE °C.
50° 100° 150° 200° 250° 300° 350°

FIG. 9.

A denser texture with less graphite and as much combined carbon offers a substantial resistance to the ball at the beginning, and results in high Brinell figures without the matrix proper being harder than in the preceding instance. The aluminium silicon piston alloys used in Germany, containing up to 20 per cent. silicon, which of course shows a high percentage of hyper-eutectic with very hard silicon crystals, nevertheless gives comparatively low Brinell figures, since under the pressure of the ball the silicon crystals are pressed into the soft matrix without offering any sensible resistance by themselves. In spite of the low Brinell hardness, amounting to about 80 only, this alloy has an extremely high wearing coefficient, higher than for treated aluminium copper with Brinell up to 140, but unfortunately this alloy with its low coefficient of heat conductivity and its low strength at elevated temperatures, and also the difficulty of obtaining uniform castings and structure due to the hyper-eutectic of Si, has not been

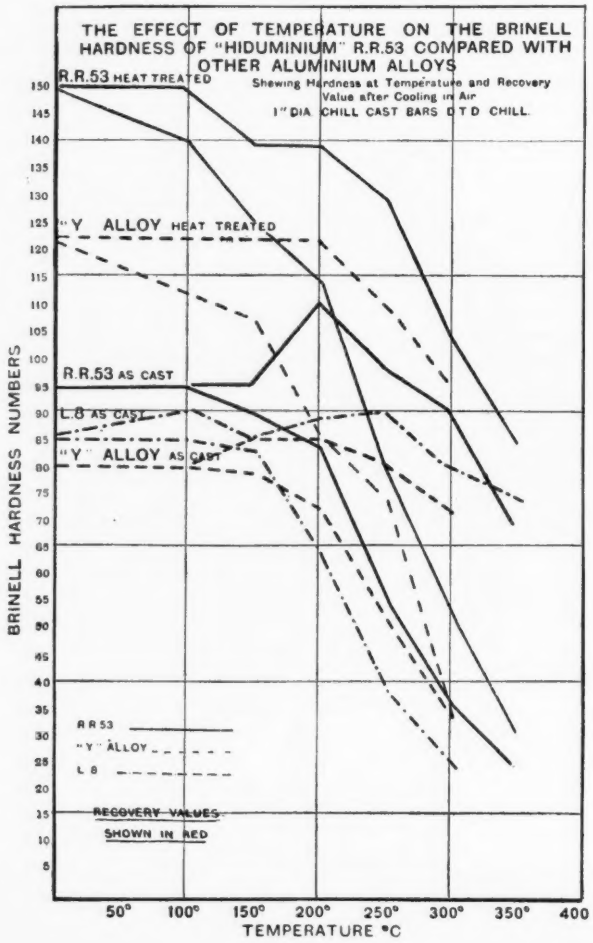


FIG. 10.

entirely successful when used in piston construction. The " Hiduminium " R.R.53 material has good strength at elevated temperature, as is shown by slide Fig. 9, and the influence of the temperature on the Brinell hardness in comparison with other aluminium piston alloys is shown in Fig. 10. An attempt to measure the friction properties has been done on a machine as Fig. 11, the motor driving a spindle to which is attached the chuck containing four discs of the material under test, which run in an oil bath working under whatever temperature is required, the discs running on a steel or cast iron disc. Fig. 12 shows a curve of friction

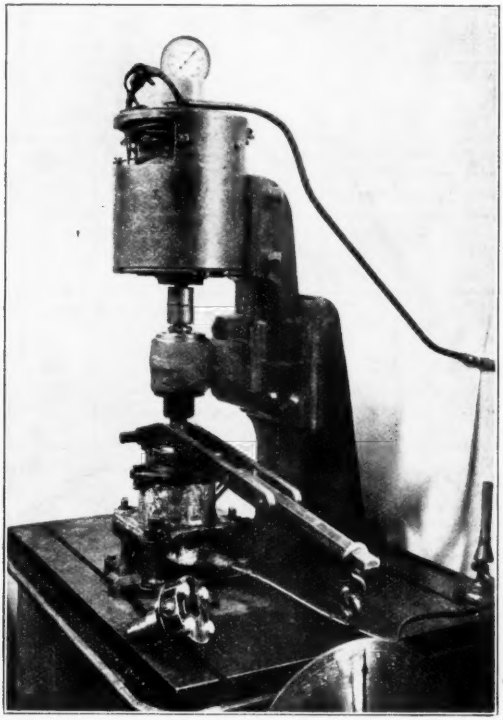


FIG. 11.

test taken on this machine where the oil was standard P.4, and the aluminium alloys were tested against a steel disc of .4 per cent. carbon steel (B.E.S.A. S.70), and this was loaded to 100lbs. per sq. inch and runs at 545 r.p.m. Amperes give the measure of relative friction. Fig. 13 gives the fatigue test curves of various chill cast alloys.

" Y " alloy is exceedingly good as a piston material, but when used in the die or sand cast form is a particularly difficult material to cast. " Y " alloy for years has served a most useful purpose, and it is distressing to think that this material which was developed—or rather introduced—by our own National Physical Laboratory has been more extensively used abroad than in this country. At the time that this alloy was coming into prominence in this country other alloys, namely, the R.R. alloys developed on parallel lines with the " Y " alloy, had begun to supplant this most excellent material.

To come now to air-cooled engines; the successful development of the air-cooled motor has been largely responsible for the tremendous growth in commercial aviation, particularly during the past few years. Since these engines depend for their cooling upon the rapid flow of air round the cylinders, and particularly around the cylinder head, the aluminium alloys recently developed, with their high thermal conductivity, have proved most useful. Naturally in the air-cooled motor temperatures are higher, and materials must be selected particu-

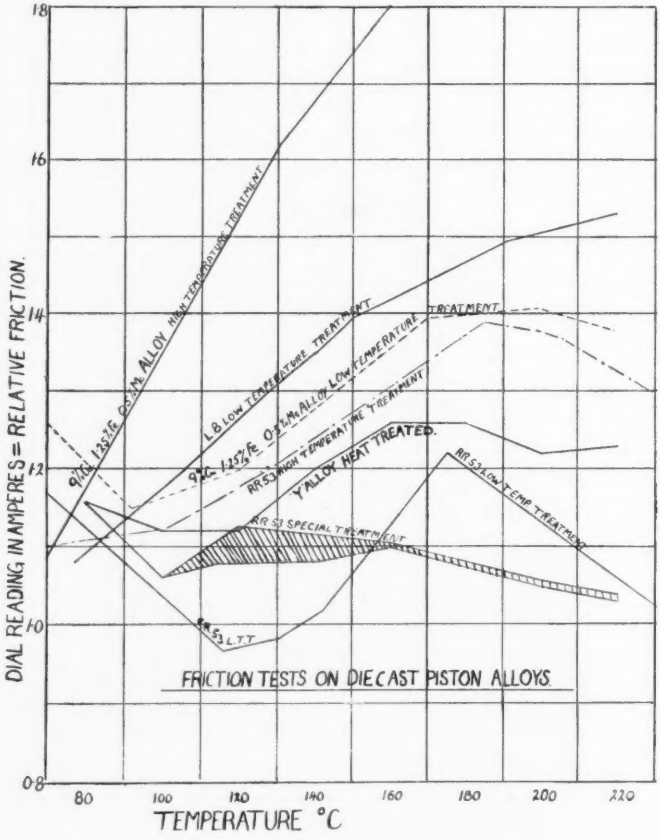


FIG. 12.

larly in regard to their strength at high temperatures. This largely has made the way for the almost universal use of forged materials in the design of air-cooled motors.

Fig. 14 shows some large crankcase stampings made in " Hiduminium " R.R.56 material; the lower ones show " Panther " crankcase stampings and the upper stampings show those of the " Mercury " and " Pegasus " type. These are typical examples of strength with lightness, this material being pre-eminent in this respect, having in the actual stamping .1 per cent. proof stress of 23 tons per sq. inch, and ultimate strength of 28 to 30 tons per sq. inch, and elongation

of 10 to 15 per cent., and a Brinell hardness of 130 to 140. In addition to which it is a particularly easy material to forge, and by its very ease of casting in the ingot, and its subsequent ease of forging, ensures good homogeneous structure throughout its mass.

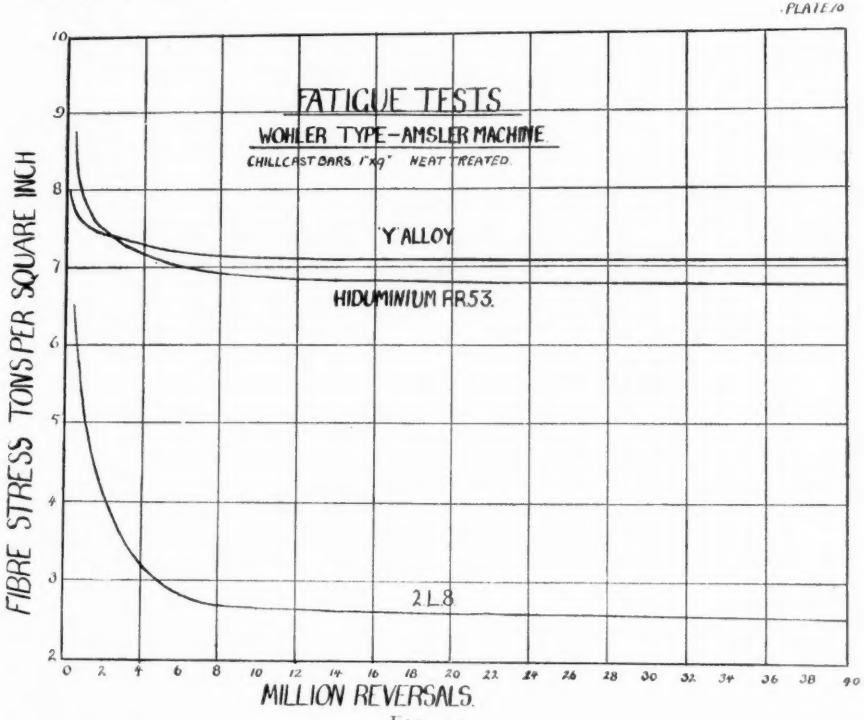


FIG. 13.

Fig. 15 shows a group of assorted stampings typical in general of aircraft requirements, with the exception, of course, of the very large connecting rod

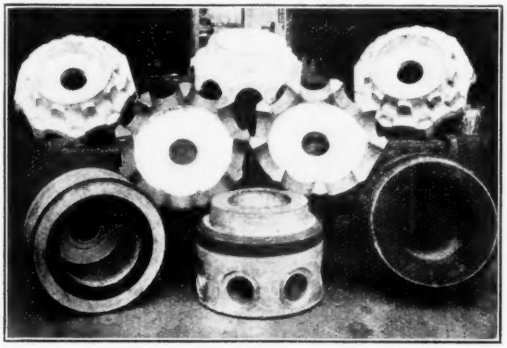


FIG. 14.

shown across the table which is one of six rods that are in experimental use on the L.N.E. Railway.

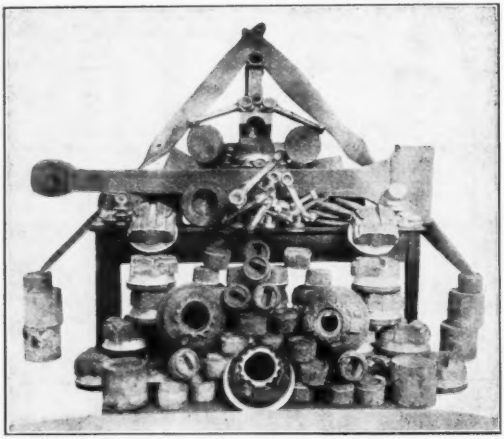


FIG. 15.

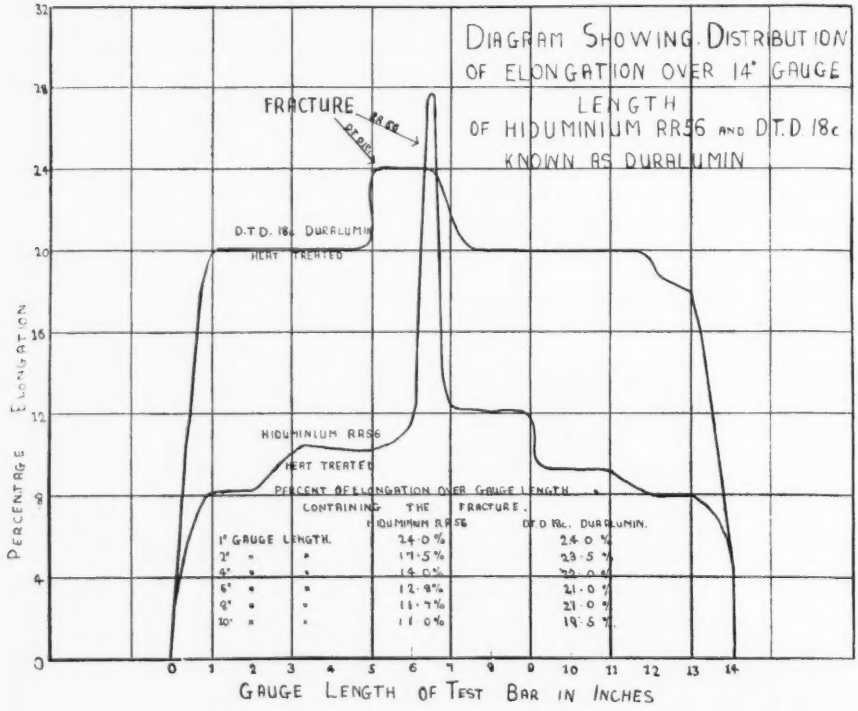


DIAGRAM SHOWING DISTRIBUTION OF ELONGATION OVER 14" GAUGE LENGTH OF HIDUMINIUM RR56 AND D.T.D 18c KNOWN AS DURALUMIN
FRACTURE
D.T.D. 18c DURALUMIN HEAT TREATED
HIDUMINIUM RR56 HEAT TREATED
PERCENT OF ELONGATION OVER GAUGE LENGTH CONTAINING THE FRACTURE.
HIDUMINIUM RR56
D.T.D 18c. DURALUMIN.
1" GAUGE LENGTH. 24·0 % 24·0 %
2" " " 17·5 % 23·5 %
4" " " 14·0 % 22·0 %
6" " " 12·8 % 21·0 %
8" " " 11·7 % 21·0 %
10" " " 11·0 % 19·5 %
PERCENTAGE ELONGATION
0 4 8 12 16 20 24 28 32
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
GAUGE LENGTH OF TEST BAR IN INCHES

FIG. 16.

Whilst on the question of wrought alloys, I wish to point out a general aspect in relation to elongation and its value. Extraordinary differences are indicated in the elongation diagram shown in Fig. 16; this shows the distribution of elongation taken over a 14in. gauge length of duralumin and R.R.56 material. The reason for this phenomenon will be apparent as the effect of crystal size and formation is considered; actually crystal slip takes place over the full length of the bar to a greater extent in the duralumin than in the R.R.56, which indicates what is now becoming increasingly well known, that designers must be diffident in taking the elongation figure over the 2in. gauge length as being a direct measure of the ability of a material to accommodate a local over-stress. This is emphasised in tests carried out on a machine (Fig. 17) with a reciprocating motion

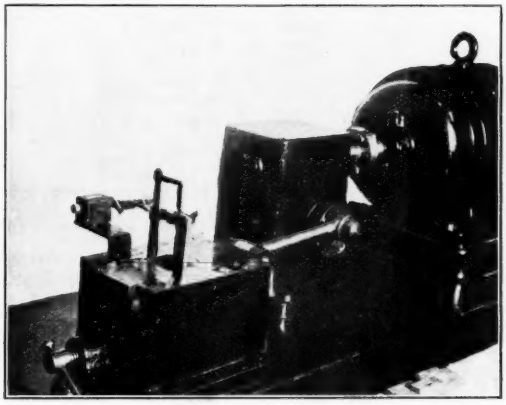


FIG. 17.

TABLE II.

DEFLECTION FATIGUE RESULTS ON HEAT TREATED BARS.

Deflection. Distance from Vertical	Total Angle	Number of Reversals to Fracture. R.R.56	Y Alloy	DTD.18.C. as Duralumin	Mild Steel Normalised
$\frac{1}{8}''$	4° 40″	26,246	20,495	20,771	4,758
$\frac{5}{32}''$	5° 50″	9,820	6,583	7,472	4,990
$\frac{3}{16}''$	7° 0″	8,109	6,378	5,093	4,624

Each figure is the average of six tests.
Mild Steel takes a severe permanent set from the first bend at each deflection.

which produces an effect that may be called deflection fatigue. The machine operates at 42 reversals a minute on test pieces cut from 1in. square forged bar, heat treated to give the specification figure, machined all over, and polished to a high finish. The speed was purposely slow in order to avoid shock. The results of these tests are given in Table II, in which it will be seen that the material with the highest elastic limit, although lower on the elongation figure, has come out best.

Confirmation of this is given by P. Ludwick, in a paper read before the New International Association for Testing Materials, at Zurich, in September, in which he states: "The resistance to alternating stress of metals with polished surfaces is dependent on the resistance to deformation, and not on the ability to undergo deformation. Great resistance to deformation was frequently found in conjunction with high sensitivity under impact."

The results of the mild steel specimen in this test follow the theoretical consideration which shows that aluminium will absorb considerably more energy than steel under the same dynamic load, by virtue of its lower modulus of elasticity,

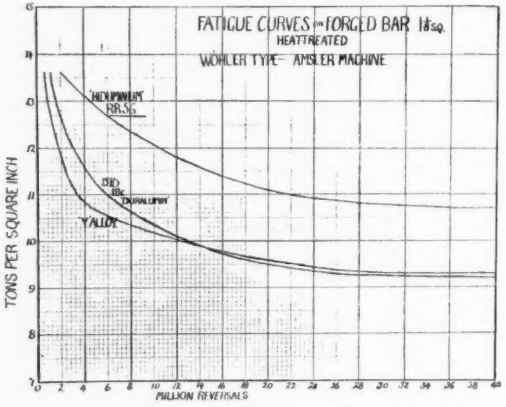


FIG. 18.

this holding good so long as the stresses are kept below the elastic limit. Fig. 18 gives the Wohler fatigue figure for material taken from 1⅛in. square forged bar, heat treated and machined at the point of maximum bending moment to 0.52in. diameter.

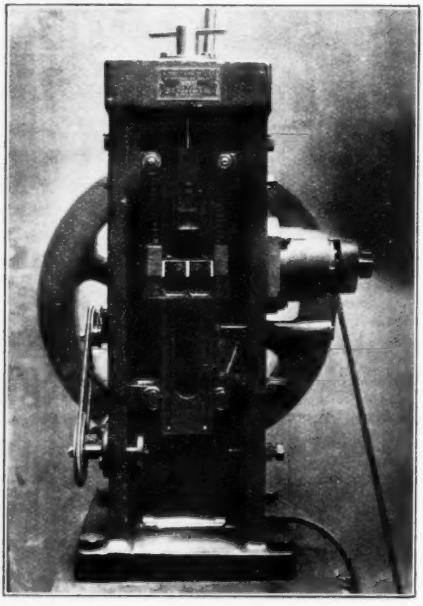


FIG. 19.

Further interesting evidence between elongation and high elastic limit as applied to various materials is given on the Amsler repeated impact test, the machine for which is shown in Fig. 19. This machine combines an impact with a fatigue effect. The higher the energy factor is made in this test the greater will be the difference between two materials having similar ultimate tensile strengths, but considerably different yield points.

TABLE III.

AMSLER REPEATED IMPACT TEST

All tests taken from 1¼"sq. forged bar heat treated to give specification figures
The results at each setting of six tests are given

1st. SERIES
ENERGY OF BLOW 1.16 ft. lb.
NO. OF BLOWS PER MINUTE 630.

TEST	R.R.56	"V" ALLOY	DURAL.
1.	4770	170	160
2.	6320	210	150
3.	6335	200	150
4.	5060	210	145
5.	4510	165	150
6.	6820	165	150
Highest.	6820	210	160
Lowest.	4510	165	145
Average.	5626	187	151

2nd. SERIES
ENERGY OF BLOW 0.517 ft. lb.
NO. OF BLOWS PER MINUTE 630.

TEST	R.R.56	"V" ALLOY	DURAL.
1.	103,770	83,030	34,440
2.	98,000	70,050	39,820
3.	100,500	65,850	39,420
4.	107,210	52,500	32,450
5.	105,360	58,800	41,760
6.	90,150	–	—
Highest.	105,360	70,050	41,760
Lowest	90,150	52,500	32,450
Average.	100,832	50,038	37,578

3rd SERIES
ENERGY OF BLOW 0.351 ft. lb.
NO. OF BLOWS PER MINUTE 840.

TEST	R.R.56.	"V" ALLOY	DURAL.
1.	328,100	113,180	99,450
2.	230,300	69,980	67,580
3.	370,920	159,920	90,440
4.	267,110	148,520	118,100
5.	197,970	107,870	72,000
6	324,820	105,780	64,870
Highest.	370,920	159,920	118,100
Lowest.	197,970	69,980	64,870
Average.	276,218	117,541	84,906

4th SERIES
ENERGY OF BLOW 0.150 ft. lb.
NO. OF BLOWS PER MINUTE 840.

TEST	R.R.56	"V" ALLOY	DURAL.
1.	1,000,000	255,460	226,430
2.	1,000,000	255,940	333,970
3.	1,000,000	478,800	195,620
4.	1,000,000	148,470	247,530
5.	1,923,000	619,150	224,290
6.	All above tests unbroken	361,840	248,440
Highest.		619,150	333,970
Lowest.	Unbroken	148,470	195,620
Average.	–	353,276	246,045

Without going into the why or wherefore of the general design conditions coming under this Amsler universal impact machine, it is my view that under general design conditions the Amsler universal impact testing machine more

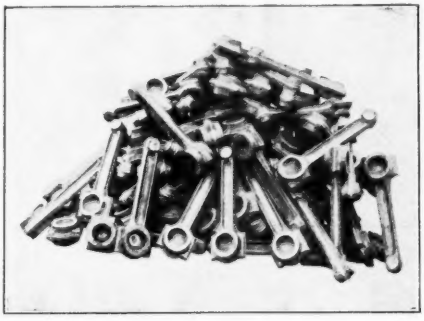


FIG. 20.

nearly approaches the working conditions of most parts in service than any other test. In this statement we must keep in mind the fact that the Wohler reverse bending fatigue test does not represent usual practice due to the fact that the test is safeguarded against the smallest vibration, whilst on the other hand the Arnold type of test which gives a few reversals, each reversal being of such

magnitude as to pass the yield point again should not occur in practice. The test which represents practice must combine an impact with a fatigue effect, particularly in aircraft construction, as applied to the engine; Table III shows the results of tests taken on the aforesaid machine.

The connecting rods of a radial engine are obviously not of suitable design for aluminium alloy construction, but an interesting application of aluminium alloys to the connecting rods of a straight in line air-cooled engine, as used in the " Gypsy " engine of De Havilland, is given in the connecting rod shown on plate Fig. 20. These are made from forged bar.

As you will all be interested in the defects to look for in inspection, I will endeavour to give you an insight as to the methods used in my company.

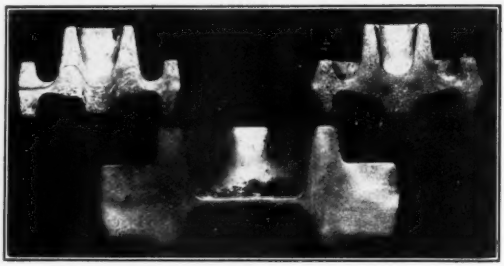


FIG. 21.

In stamping, the effects of using correct and incorrect dummy size are not always obvious, but are of paramount importance if consistent results are to be obtained. Fig. 21 shows the effect of using correct and incorrect dummy size; " A " shows a split through the flash line through using too large a dummy;

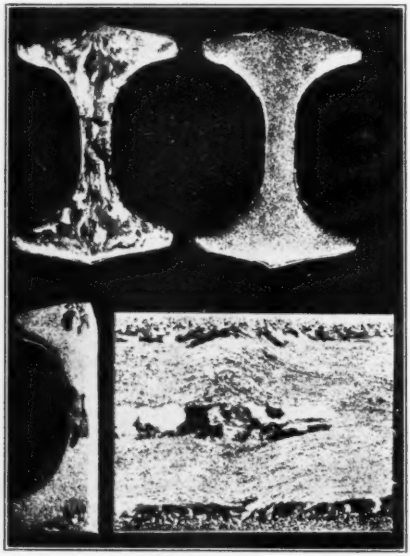


FIG. 22.

" B " shows an intermediate stage in which, though splitting has not occurred, a distinct plane of weakness is seen; while " C " is a beautiful structure made from correct size dummy. Obviously the only sure method of guaranteeing the designer uniformity in the parts interpreting his ideas is that every dummy should be inspected before going into the design; this is an invariable rule with the company with which I am associated. Of course, this means that the first stamping produced must be cut up and etched for uniformity of structure; it is our practice, therefore, in making the first stamping to first make two dummies, one which goes into the die, the other being kept until the results of the stampings are known.

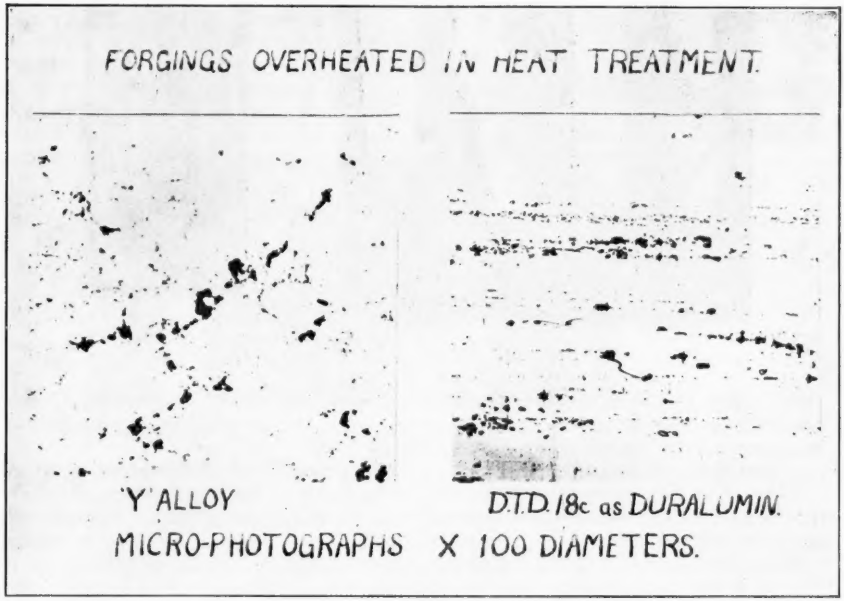


FIG. 23.

Another defect to look for is that shown on Fig. 22 where you see variations in crystal structure in the sections of a connecting rod; " A " showing mixed size crystals; " B " all large crystals; and " C " the correct macro structure.

I do not intend to go into the details of the effect of these various size crystal grains, as they have all been given in another paper which you can easily obtain, except to say that the effect of the all large crystals would be to reduce the proof stress and fatigue, and herein it is noticed that the elongation over any set gauge length is increased merely due to the fact that these enlarged crystals slip continuously throughout the length of the piece tested. This is obviously not an indication that the larger crystal would withstand any greater degree of over-stress. With regard to a part containing the mixed crystals in any over-stress, the larger crystals would slip, throwing an undue amount of stress on to the portion containing the smaller crystals; the ideal structure, of course, is the uniform one as shown at " C."

There is one disturbing fact arising out of the low figures quoted in specifications, whether of D.T.D. origin or the British Standard Specification. On most

of the light alloys the physical properties are sufficiently low as not to be indicative of overheating of any of the material. There are two methods available for detecting overheating; one is to micro-photograph the specimen, in which case tests similar to those shown in Fig. 23 will be shown, one is for " Y " alloy, the other is for duralumin; you will notice the pooling of the eutectic on reaching overheating; in the duralumin will be noticed the more laminated structure. The other method is to provide strips of material which may be heat treated at the same time as the part of importance—Fig. 24 shows such strips; these may be

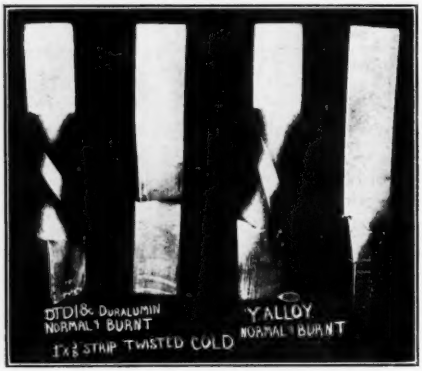


FIG. 24.

FIG. 25.

1in. by ⅛in. and may be twisted cold after heat treatment. If overheating has occurred the specimens will break off short, but if the correct heat treatment has been applied the full twist, as shown, can be obtained.

You will, of course, realise that if one is merely on the borders of overheating, and not seriously overheated, it is quite possible to obtain excellent tensile figures, but one would obtain poor results in fatigue testing. For aircraft use extruded sections are in great demand, and there is no reason why extruded sections should not be used, but the degree of inspection should be other than it is now in most factories to prevent parts getting into service which have been

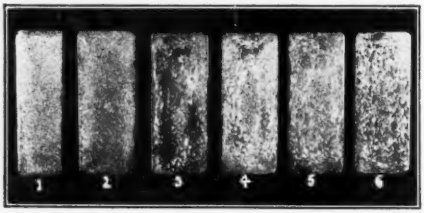


FIG. 26.

Effect of temperature on extruded bar.

(1) 1 *hr.* 530 *deg. C. quenched.*
(2) 2 *hrs.* 490-500 *deg. C. quenched.*
(3) 12 *hrs.* 490-500 *deg. C. quenched.*
(4) 12 *hrs.* 490-500 *deg. C. quenched and aged.*
(5) 24 *hrs.* 490-500 *deg. C. quenched.*
(6) 24 *hrs.* 490-500 *deg. C. quenched and aged.*

maltreated in manufacture, and it is a very simple thing to produce work of a nature shown on Fig. 25. This shows a very common defect which is due to the slipping of the core of the ingot during the extrusion process. A test of this nature should be taken at least one foot from the tag end of a bar. This defect is invariably found if taken nearer to that end, and this phenomena is apparent in all extruded aluminium alloy sections and is not confined to any one material. Plastic deformation of the material during extrusion is done at a certain temperature and time, and is such that subsequent heating for a length of time will cause growth of the crystal. Fig. 26 shows some sections of extruded bar which have been soaked at various times, one shows such material one hour after soaking at 530°C. and quenched, other soaking periods are shown on a table at the foot of the plate. Fig. 27 shows a similar effect with forged bar. The same effect is apparent with these sections as with the connecting rod section that I have mentioned previously.

I do not wish to bore you by going into the various theories expounded to account for the strengthening in aluminium alloys due to heat treatment; it is sufficient for me to say that in an alloy where some constituent is more soluble at high than at low temperature the constituent going into solid solution and is

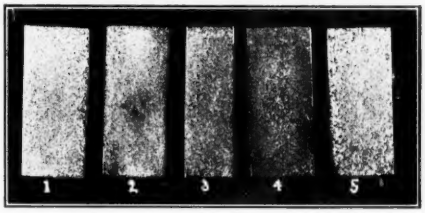


FIG. 27.

Effect of soaks on forged bar.

(1) 1 *hr.* 530 *deg. C. quenched.*
(2) 2 *hrs.* 530 *deg. C. quenched and aged.*
(3) 2 *hrs.* 490 *deg. C. quenched.*
(4) 12 *hrs.* 490-500 *deg. C. quenched and aged.*
(5) 24 *hrs.* 490-500 *deg. C. quenched and aged.*

fixed in solid solution by rapid cooling, being super-saturated and metastable at lowered temperatures, there is a natural tendency, slowly at ordinary temperatures, and more rapidly if the temperature is slightly raised, to precipitate out of solid solution some of the dissolved constituents. This occurs in the form of sub-microscopic particles distributed throughout the mass of the solid solution, and this causes hardening and strengthening. This is the theory that has been expounded to account for the phenomena. There is no direct evidence that such precipitation occurs, as at even quite high magnifications no micrographic evidence is forthcoming. The theory is useful in giving something understandable to work upon until further evidence is forthcoming.

You know that with alloys such as " Duralumin " an occurrence similar to that explained occurs, and that working, bending, etc., can be carried out much more effectively immediately after the solution treatment than before age hardening has occurred, but after even 24 hours the alloy becomes increasingly difficult to work; this leads up to a very sterling feature with the " Hiduminium " R.R.56, which will readily be apparent to you. In the case of the " Hiduminium " R.R.56 alloy it is possible to keep it in this very ductile state for considerable periods extending into some months, therefore the material can be supplied with

the high temperature treatment carried out—which is more easily carried out in the suppliers' works than in most aircraft factories—then after suitable working or bending that is necessary has been done on the part, a very simple, shall we say, precipitation can be carried out. Precipitation in the R.R.56 alloy not occurring at room temperatures, an elevated temperature of from 160°C. to 200°C. by varying the lengths of time to carry out is needed. It is supposed that the high iron content is responsible for the interference in precipitation at room temperatures. Again no direct evidence is forthcoming, but it is possible that in the atomic dispersion of the soluble heat treatment constituents it is not the dispersion that produces the maximum hardness but some intermediate one between it and that at which the particles become microscopically visible. There is scarcely any adhesion between the matrix and the constituents of heat treatment molecules precipitated from the aluminium crystals, and when these particles get to a certain size the maximum adhesion is produced; it may be then that the iron in the form of an Al_3Fe compound interferes with the seeming growth of the particle. At any rate the property is there, and use can also be made of this by obtaining strengths and elongation particular to the requirements of the designers, such figures being shown on Tables IV and IV*a*.

TABLE IV.

AS QUENCHED FROM 520°C.

Temp. °C.	Time Hours.	.1% P.S.	Y.P.	M.S.	E.1/2.	R.A.%.	Brinell.
		6.4	13.0	22.4	23.0	44.0	87.
		9.6	13.4	22.2	20.5	44.0	86.
		8.2	12.9	22.0	22.0	43.0	85.
		6.6	13.3	21.8	30.0	40.0	85.
100°C.	2.	11.2	14.4	24.2	23.0	38.0	106.
	5.	11.5	14.6	25.1	23.5	36.0	110.
	10.	12.6	15.4	25.8	24.5	35.0	114.
	15.	12.8	15.6	25.8	24.0	34.0	117.
	20.	12.3.	15.5	24.8	26.0	32.0	114.
150°C.	2.	13.0	16.0	24.5	22.0	29.0	110.
	5.	15.6	19.4	24.5	16.0	29.0	121.
	10.	17.0	20.2	27.1	19.5	29.0	125.
	15.	16.4	19.6	25.8	21.5	34.0	129.
	20.	17.6	20.8	27.0	21.0	22.0	129.
170°C.	2.	13.6	17.0	24.6	24.0	36.0	114.
	5.	18.0	22.5	27.6	24.0	38.0	129.
	10.	20.6	24.0	29.2	15.0	22.0	138.
	15.	21.0	24.2	27.2	11.0	24.0	134.
	20.	21.0	24.6	27.6	13.5	21.0	134.
200°C.	2.	20.6	24.0	27.0	15.0	26.0	125.
	5.	20.8	25.0	28.2	13.5	27.0	134.
	10.	20.4	24.6	27.0	12.5	28.0	129.
	15.	20.0	23.3	25.8	14.5	34.0	125.
	20.	20.0	23.0	25.6	13.0	32.0	117.
250°C.	2.	16.6	19.0	22.0	13.0	21.0	107.
	5.	14.7	17.2	20.6	14.0	34.0	101.
	10.	13.2	15.1	19.6	11.5	30.0	98.

TABLE IVA.

HIGH DUTY ALLOYS LIMITED.

SLOUGH.

Laboratory.

REPORT ON THE INVESTIGATION ON THE HEAT TREATMENT OF "HIDURIMIUM" R.R.56.

PHYSICAL TESTS:

AS QUENCHED FROM 530°C.

.1% Proof Stress.	Yield Point.	Max. Stress.	Elongation .1%.	Redn. of Area %.	Brinell Hardness.
11.0	15.2	23.2	21.0	32.0	97.

AFTER ARTIFICIAL AGING.

Temp. °C.	Time Hours.	.1% P.S.	Y.P.	M.S.	E. .1%.	R.A.%.	Brinell
100°C.	2.	13.0	15.0	24.4	23.5	30.0	107.
	5.	13.8	16.6	25.3	27.0	29.0	114.
	10.	13.6	16.0	25.0	29.0	47.0	114.
	15.	13.8	16.0	25.4	20.0	34.0	117.
	20.	13.7	15.8	25.8	27.0	46.0	114.
150°C.	2.	14.0	17.8	25.5	20.0	32.0	114.
	5.	15.2	19.2	26.2	21.0	33.0	114.
	10.	17.0	21.2	27.6	24.5	42.0	129.
	15.	17.6	20.6	27.0	16.0	24.0	129.
	20.	17.5	20.4	26.8	18.0	24.0	128.
170°C.	2.	18.0	20.8	26.8	17.0	30.0	125.
	5.	18.8	21.6	26.0	19.0	32.0	134.
	10.	21.2	25.4	29.0	14.0	33.0	148.
	15.	22.0	26.2	29.0	11.0	20.0	134.
	20.	23.4	26.4	29.8	12.5	26.0	129.
200°C.	2.	22.4	26.8	29.6	15.0	25.0	129.
	5.	21.8	26.0	29.5	14.0	30.0	138.
	10.	21.0	24.0	27.0	15.0	25.0	129.
	15.	21.2	25.2	28.8	10.5	21.0	121.
	20.	20.4	24.2	27.0	11.0	21.0	121.
250°C.	2.	16.2	19.2	22.8	12.0	29.0	110.
	5.	15.4	17.2	21.7	14.5	34.0	101.
	10.	13.8	16.2	20.4	13.0	31.0	95.

The development of the air-cooled aircraft engine has brought out troubles which have not been experienced with the water-cooled engine, mainly in the piston. These troubles have been overcome, apart from the improvements in design, by the development of stronger aluminium alloys to cope with the high temperatures met not only in the cylinder head, but in the piston itself, and now the forged piston is mostly used not only in this country but abroad. It is possible in a forging to get a material which has a greater density, one which is more consistent, very strong at temperatures and with a higher heat conductivity. The materials mostly used are " Y " alloy and the " Hiduminium " R.R.59. There is not much to choose between them in actual physical properties at other than normal temperatures, but the R.R.59 does have a slight advantage. The wearing properties are better with the R.R.59 material; the thermal expansion is slightly lower; the heat conductivity slightly better. The principal advantage lies in that it is more easy to manufacture, enabling more consistent results to be obtained. Apart from this it is approximately 2½ per cent. lighter. Recently

there have been introduced the high magnesium aluminium alloys under the name of MG7 and " Hiduminium " R.R.66. These alloys are approximately 5 per cent. lighter than " Duralumin," their principal characteristics being the high resistance to corrosion. In the annealed condition in which they are most workable they do not compare favourably in strength or corrosion with the anodically treated Duralumins. These materials gain their strength by cold work, but owing to the difficulty in working they have not yet developed as was hoped. Research is being continued, and it is hoped that the difficulties now experienced will be overcome. Magnesium alloys, whether in the cast or wrought condition, have not yet much place in aircraft, or aircraft engine design, either in this country

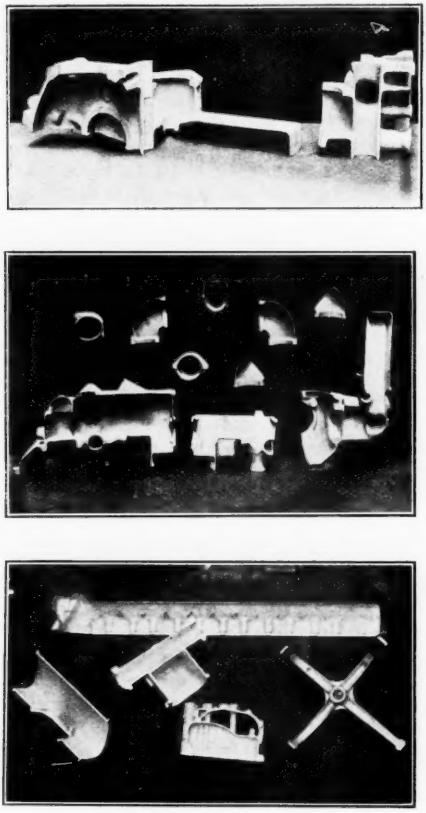


FIG. 28.

or abroad. In the cast condition, where rigidity is of paramount importance and webbing has not been possible, the magnesium cast alloys have proved useful. For really stressed parts the aluminium alloys well hold the field, and while I realise fully that in the development of aircraft and engines these materials can both have a place, in the present state of knowledge there does not seem to be much hope of the wrought magnesium alloys for the highly stressed parts.

Before I conclude I should mention one thing previously forgotten, that is

that by the introduction into production of a new flux and new technique it is now possible to produce extremely thin aluminium alloy castings, and I show you on Fig. 28 some castings now made in production, the average thickness of these being 1/10th of 1/8th inch thick, as you see over comparatively large areas.

I will now conclude my paper by thanking my laboratory staff for their assistance in preparing the plates and tables shown.

Discussion

Mr. Cantrill: There was not much difference between " Y " and R.R.59 as far as he could see; that in the present stage of design the limitations in engine design rested with the piston. What was being done to improve the qualities of the piston? And in design, what characteristics should be most sought for, maximum stress, elongation, or fatigue stress, when considering light alloys?

Mr. Wareham: It was noticed that the Brinell hardness was noticeably lowered after the piston had been in operation. Could this not be restored by suitable heat treatment at the stripping of the engine?

A Member: He was disappointed to learn that MG7 and R.R.66 were not yet suitable for parts which required much work in bending. Would it not be possible to effect some lightness by using aluminium alloys for electric cables?

Mr. Hodges: He had always been under the impression that magnesium, added to aluminium, increased the liability to corrode. He was surprised to learn that the materials now put forward for non-corrosive properties contained magnesium as high as 5 and 7 per cent.

A Member: He had experienced considerable trouble when using " Y " alloy for pistons, with the material growing after machining, and he was sorry Mr. Devereux had not given some information as to the de-gasifying processes used.

A Member: He had noticed Mr. Devereux's advice to include so much laboratory control and inspection, but he had observed such difficulty with buyers generally that he doubted if it could be economically done, and the buyer would certainly not pay for it.

Reply to Discussion

There was not much difference in " Y " alloy and R.R.59 in physical properties at elevated temperatures, but what difference there is, is slightly in favour of R.R.59, which is more easily forged and gives more consistent results.

He agreed that the limitation in the air engine seemed to be the piston, and much work was in progress in an endeavour to improve the properties of the materials. Mr. Cantrill would appreciate that research work, as far as metallurgy was concerned, was confined to the limited means at his disposal in the laboratory, and before much development could take place there must not be the secretiveness at the engine manufacturers' own works; they should be more readily disposed to give to the metallurgists more exact particulars of the troubles they experienced in running, then no doubt progress would more rapidly be made.

The question of which was the main property of the material to judge for your design rests, of course, with the application to which the material was being put; obviously, for a propeller blade fatigue stress would be the ruling factor; for purely static load the yield point, and for a part called upon to withstand cold work during manufacture a high percentage of elongation would be desirable.

In answering Mr. Wareham, Mr. Devereux replied that the Brinell hardness could be restored by heat treatment, which would necessitate taking the materials to a temperature of 520-530°C., and this would probably give trouble with distortion. In answer to the further question regarding MG7 and R.R.66

applications, much development work was being done to improve these alloys in order to make them available for parts that in production needed amounts of cold work.

It was quite possible that some saving in weight might be made by the use of electric cables of aluminium. It was well known that aluminium alloys on the Continent were playing an enormous part in overhead transmission cables.

In answer to Mr. Hodges, it was true that certain additions of magnesium did accelerate liability to corrosion, but there becomes a stage where constituents formed in the alloy had equal electric chemical equivalents, and in the case of the magnesium alloys these seemed to be between 4 and 10 per cent., in which case the alloys withstood saline solution corrosion extremely well. In answer to the further question, " Y " alloy and R.R.59 did not grow after heat treatment. The reason for the growth experienced in " Y " alloy was usually found to be the use of inferior material that contained gas inclusions. It was not possible to mention all de-gasifying processes in the short time at the speaker's disposal, but much work had been done in this direction, but the processes were cumber some and hardly suitable for ordinary commercial use. The speaker's firm had only this year introduced a remarkable flux which had proved to be as good, and in some instances better, than the de-gasifying processes used up to date, and certainly more commercial. It was hoped that during the next month an R.A.E. report would be issued which would confirm this.

Mr. Devereux replied to the last member that the buyer was perfectly justified, and in fact only doing his duty, if he purchased in the lowest market, but he surely expected that in the tender was included the honest undertaking to give him 100 per cent. in the quality of the goods bought. However, apart from this, it was the author's experience that laboratory control and inspection could both be put on a production basis and, contrary to proving expensive, had been the means in his factory of effecting considerable saving.

WING-BEATS III

BY

J. D. BATTEN

On the assumption that for winged flight a man would have to rely on the *phasic* activity of his muscles (that is to say on an activity induced by nerve impulses from the brain at a rate of 50 per second, or thereabouts) it is easy to believe that for man such flight is impossible.

On a like assumption it is also impossible for birds.

It is only by recognition of the probability that a bird's great pectoral muscles are, to a large extent, " anti-gravity muscles " and as such exercise a *postural* function " almost incapable of fatigue "[1] that the long sustained flights of migratory birds can in any measure be comprehended.

Although the distinction between the *phasic* and the *postural* activity of muscle is of recent definition, the existence of such dual function in the case of bird flight was clearly recognised by a pioneer of British aeronautics, Francis Herbert Wenham.

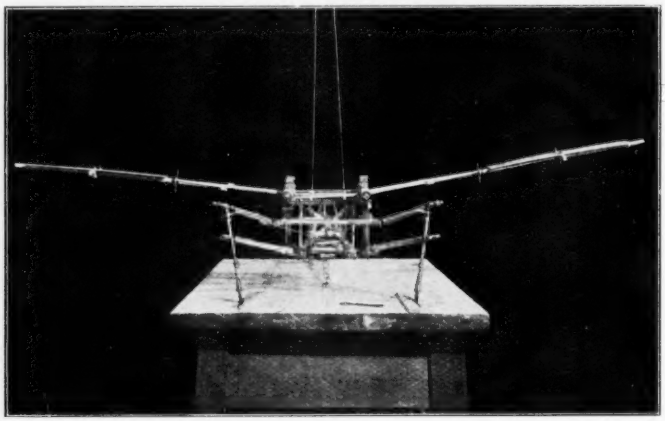


FIG. 1.

In a paper read at the first meeting of the Aeronautical Society in 1866, Wenham writes:—" Anatomists state that the pectoral muscles for giving motion to the wings are excessively large and strong; but this furnishes no proof of the expenditure of a great amount of force in the act of flying. The wings are hinged to the body like two powerful levers, and some counteracting force of a *passive* nature, acting like a spring under tension, must be requisite merely to

[1] See: Proceedings of the Royal Society of Medicine, Section of Orthopædics; Presidential Address " The Physiology of Muscular Action," by A. S. Blundell Bankart, M.Ch., Oct. 6th, 1925; from § beginning " It is now known that the skeletal muscles exhibit two kinds of activity."

balance the weight of the bird. It cannot be shown that while there is no active motion, there is any real exertion of muscular force; for instance, during the time when a bird is soaring with motionless wings. This must be considered as a state of equilibrium, the downward spring and elasticity of the wings serving to support the body; the muscles, in such a case, performing like stretched indiarubber springs would do. The motion or active power required for the performance of flight must be considered exclusive of this."[2]

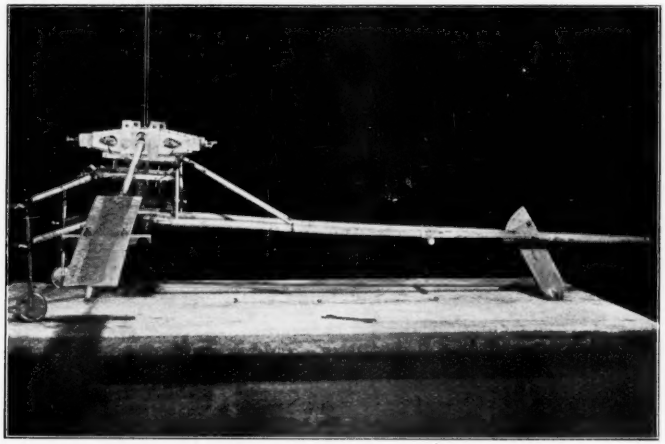


FIG. 2.

[2] Reprinted by this Society 1910 Aeronautical Classics No. 2. The importance of Wenham's evidence justifies a longer quotation: "One of the first birds in the scale of flying magnitude is the pelican. It is seen in the streams and estuaries of warm climates, fish being its only food. On the Nile, after the inundation, it arrives in flocks of many hundreds together, having migrated from long distances. A specimen shot was found to weigh twenty-one pounds, and measured ten feet across the wings, from end to end. The pelican rises with much difficulty, but, once on the wing, appears to fly with very little exertion, notwithstanding its great weight. Their mode of progress is peculiar and graceful. They fly after a leader, in one single train. As he rises or descends, so his followers do the same in succession, imitating his movements precisely. At a distance this gives them the appearance of a long undulating ribbon, glistening under the cloudless sun of an oriental sky. During their flight they make about seventy strokes per minute with their wings. This uncouth-looking bird is somewhat whimsical in its habits. Groups of them may be seen far above the earth, at a distance from the river side, *soaring* apparently for their own pleasure. With outstretched and motionless wings, they float serenely, high in the atmosphere, for more than an hour together, traversing the same locality in circling movements. With head thrown back, and enormous bills resting on their breasts, they almost seem asleep. A few easy strokes of their wings each minute, as their momentum or velocity diminishes, serves to keep them sustained at the same level. The effort required is obviously slight and not confirmatory of the excessive amount of power said to be requisite for maintaining the flight of a bird of this weight and size. The pelican displays no symptom of being endowed with great strength, for when only slightly wounded it is easily captured, not having adequate power for effective resistance, but heavily flapping the huge wings, that should, as some imagine, give a stroke equal in vigour to the kick of a horse. During a calm evening, flocks of spoon bills take their flight directly up the river's course; as if linked together in unison, and moved by the same impulse, they alter not their relative positions, but at less than fifteen inches above the water's surface, they speed swiftly by with ease and grace inimitable, a living sheet of spotless white. Let one circumstance be remarked—though they have fleeted past at a rate of nearly thirty miles an hour, so little do they disturb the element in which they move that not a ripple of the placid bosom of the river, which they almost touch, has marked their track."

My own contribution to the problem of human flight is the suggestion that the counterpart of such *postural* muscular function might, to a large extent, be fulfilled by an artificial appliance; and I have further called attention to the suitability to this purpose of a torse of natural silk.

The experiments recorded in " Wing-Beats " I and II go a long way towards proving that, as a substitute for muscle in its *postural* function, the appliance tested is apt and adequate.[3]

If this be found true, the great impediment is passed and we are brought face to face with difficulties of construction which are not likely permanently to baffle human invention.

A difficulty from which the rotary propeller is free is inherent in propulsion by wing beats, the difficulty of finding room for a beat of sufficient amplitude while the creature or machine is on the ground.

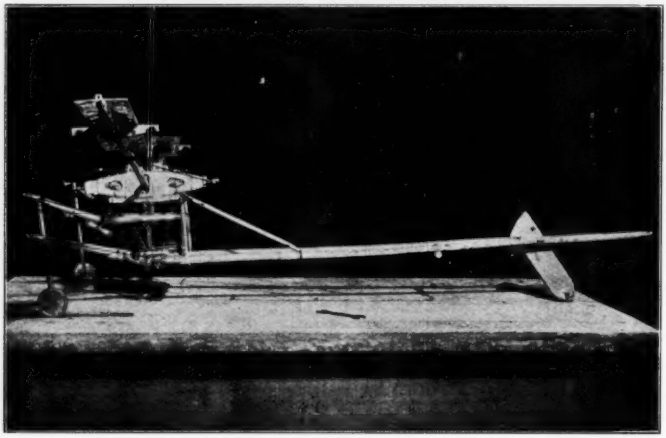


FIG. 3.

Birds which alight and roost on the branches of trees avoid this difficulty. Long-legged birds, such as the heron, have only to topple forward to find large amplitude for their first wing beats. Certain birds which live among grass and low shrubs have extraordinary leaping powers which carry them clear of encumbrances to the free movement of their wings. But a few birds of exceptional length of wing (the albatross and the swift are quoted), find it impossible to rise from a smooth flat surface.[4]

I have also found that a bat (I have kept several at various times) has difficulty in rising directly from a smooth table. It shuffles to the edge and in an instant is lost to sight.

I put these facts forward as an excuse for a human device much more complicated than I could have wished.

The small model shown in photo 1 of " Wing-Beats " II has been lifted from the brass rails upon which its wing spars were supported and has been set upon an atterrissage provision of its own.

The lead weights are no longer hung on a wooden rod as before, but are attached beneath and above the floor of a rectangular cage which now completes the thorax.

[3] Journal of this Society, October, 1930, and December, 1931.
[4] " Le Vol des Oiseaux," Marey, Paris, 1890, p. 23.

In reality the construction will not be quite as complicated as in the model, for the pieces which, in front view, are observable as an X will be absent. Their purpose is to synchronise and equalise the movements of the right and left levers, a control which should be in the hands of the aviator.

The aluminium index plates and the yokes which were useful in the former experiment had not been removed at the time when the accompanying photographs were taken. They were removed later.

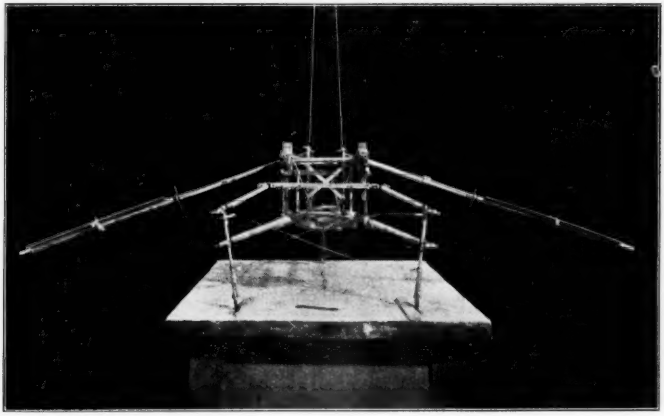


FIG. 4.

The present model was subjected to experiments similar to those recorded (" Wing-Beats " II) of the former model, and the same apparatus was used for conveying an upward pull to the butt ends of the wing spars. The cotton thread used was No. 100 sewing cotton, which is the thinnest gauge in ordinary use. Its weakness sets a definite limit to the muscular power which can be applied in the course of the experiment.

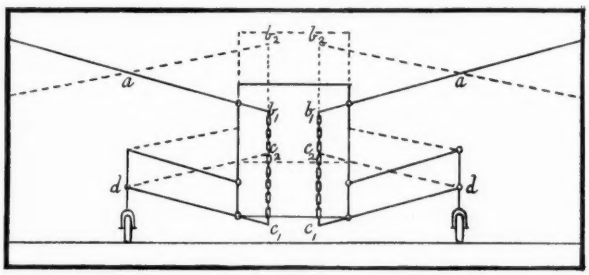


FIG. 5.

As before, a slight repeated upward pull is sufficient to induce and maintain a constant up and down oscillation of the thorax, which now expresses itself as a constant beating of the wing spars.

The evolution of the atterrissage construction was as follows:—

My first design (carried no further than the drawing stage) was as shown in Fig. 5. *aa* are the assumed centres of air support under the wings. *b* and

c are the butt ends of the wing spars and of the main atterrissage spars respectively. *cd* is made equal to *ba*. *b* and *c* are joined by a thong, cord, or chain of such length that, when taut, it makes *cd* parallel to *ba* and brings the point *d* vertically beneath the point *a*.

An obvious fault of the construction is that as the wing spars pass the horizontal, the wheels are wrenched sideways.

I therefore made a departure (shown in Fig. 6) from the true parallelogram system of the atterrissage levers.

The upper member of the atterrissage parallelogram has been divided so as to consist of (i) an outrigger GF rigidly fixed at right angles to the upright of the thorax, and (ii) of a member FE hinged to the end of this so as to move in a vertical plane.

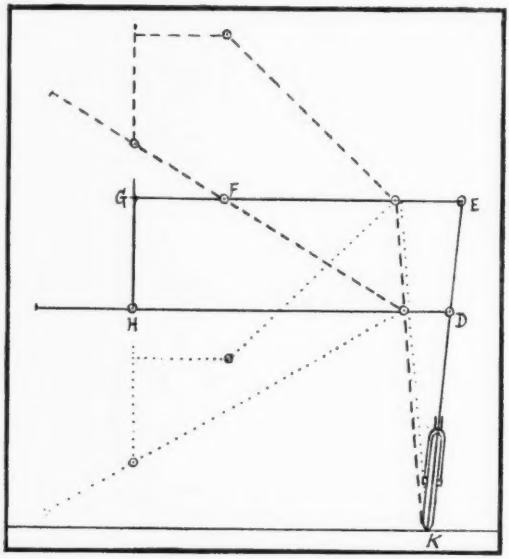


FIG. 6.

The figure shows in simple line the position of the system when the wing spars are horizontal, and in dotted and in broken lines the positions when the wing spars are inclined 30° above or below the horizontal.

I next considered whether, without loss of efficiency, I could slew the atterrissage levers from their lateral position to a position intermediate to the lateral and forward. It was evident that in such case the wing levers and the atterrissage levers would oscillate in different planes and that it would be impossible to keep the butt end of the main atterrissage lever vertically beneath the butt end of the main wing spar, but I hoped that if the cord or chain connecting the butt ends were of sufficient length the inconvenience would not be appreciable.

This construction was put into execution in the model shown in the photographs. The atterrissage levers were brought to an angle in the horizontal plane of 45° between the lateral and the forward. The wheels, however, were still set to run forward.

As far as practicable, I put this model through the same tests as those employed with the model of " Wing-Beats " II. I could not, of course, vary

the " spar length," that is to say, the distance from the torse to the assumed position of support under the wing spar; this I count to be five inches, the actual length of the main atterrissage spar from the thorax bearing to the bearing of the member above the wheel. On the other hand, I could carry the series of added weights further than before.

The net weight of the thorax in the previous experiment was 15 ounces. Certain small pieces have been removed and the whole has been connected with a further structure. I am doubtful how much of this added weight should be debited to the thorax. For the purpose of the annexed chart, I have taken the weight of the thorax at $1\frac{1}{4}$lbs. Quarter-pound lead weights can be added to this up to a total of 5lbs.

As compared with the previous experiment the amplitude of oscillation has been increased. It is now a reputed angle of 60°, that is an observed angle of 30° above the horizontal and an apparently equal angle below.

As before, the time of 100 oscillations is noted with a stop-watch; this observation is repeated six times, and the fastest time is recorded on the chart, fifth seconds being carried to the half second above.

For example, the first record was as follows:—

100	oscillations	of	60°	...	...	1	minute	$24\frac{4}{5}$ seconds.
100	,,	,,		...	...	1	,,	$24\frac{2}{5}$,,
100	,,	,,		...	...	1	,,	$23\frac{1}{5}$,,
100	,,	,,		...	...	1	,,	$22\frac{3}{5}$,,
100	,,	,,		...	...	1	,,	22 ,,
100	,,	,,		...	...	1	,,	$21\frac{4}{5}$,,

The two upper (*i.e.*, slower) paths were plotted while the aluminium index plates were still attached to the wing spars. The heavier line represents the addition to the thorax of quarter-pound lead weights, one by one, up to five pounds. The lighter line represents their removal one by one.

The two paths agree in this that the fastest oscillations occur when the thorax weight is $3\frac{1}{4}$lbs. (*i.e.*, 2lbs. of added lead). Any increase or decrease of thorax weight tends to slower movement.[5]

I next removed the aluminium plates, yokes *dc*. Their united weight was five ounces.

I then went through the same series, adding lead weights one by one. The lowest path records the oscillation times.

The fastest time is with thorax weight of $1\frac{3}{4}$lbs., *i.e.*, with added lead weight of $\frac{1}{2}$lb.

I think that that is as far as I can with advantage carry my experiments with small models. The next experiment ought to be made full scale.

The construction which I intend will be on the lines of the present model, but a position will be available for the aviator approximating to that shown in photos VI and VII of my book.[6]

The strength and endurance of the silk have proved so much greater than I had realised at that time that I now contemplate using only one pair of torses in place of the four pairs shown in the book. The torses will, however, be larger.

I submit that it is a reasonable deduction from the experiments already recorded, that the effort required of a man in order to render, full-scale, the oscillatory movement shown by the model, will be small.

That small effort will not give propulsion and consequently will not give lift, but every ounce of effort that a man can put into his stroke over and above that

[5] Certain observations of the relation between the weight of the wing and the total weight of the bird, are recorded by the late M. José Weirs in a paper entitled " Rapports des poids aux surfaces " in *L'Aerophile*, 15 Jan., 1910.

[6] " An Approach to Winged Flight," Dolphin Press, Brighton, 1928.

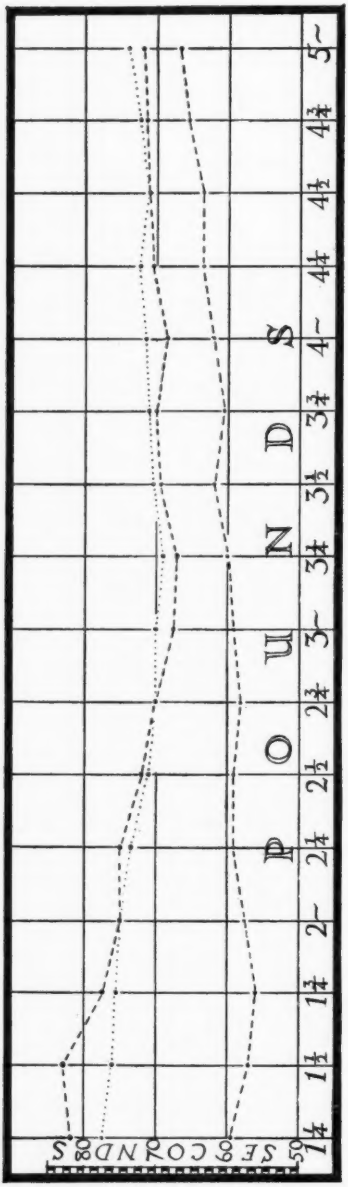


Fig. 7.

small effort will (with wings rightly constructed) tend to propulsion, and every foot per second of propulsion will (with wings rightly inclined) tend to lift.

As in the position assigned to him, a man is able to put to use the full thrust of his legs against the pull of his arms and shoulders. I believe that his success will depend upon the propulsive aptitude of the wings.

Wings

I have left the consideration of wing forms to the end, because I believe that any useful design of a moving wing will have to be founded on full-scale experiment, and no experiment seems possible until a muscular or quasi-muscular control of the simplest wing movement has been established. My project is to build on to the wing spars experimental wings or portions of wings.

The first experiments will be directed towards the design of a wing of maximum *propulsive* aptitude. A great wealth of evidence exists as to the sustaining aptitude of an aerofoil, but experiments of the propulsive power of a wing have been comparatively few.

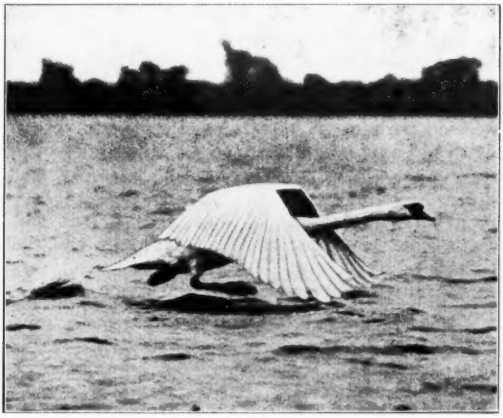


FIG. 8.

In his Preface to the British Natural History Museum handbook descriptive of the exhibits illustrating the mechanism of natural flight, the Editor makes comparison between winged flight and aeroplane flight and points out that the wing is at the same time both propeller and aerofoil.

Considered as a propeller, the wing has this in common with the rotary propeller of the aeroplane that *the path of propulsion is at right angles to the plane of the blade stroke*.

It follows from this that the downward forward beat of a bird's wing (attested by innumerable photographs) imparts to the body of the bird propulsion in an ascending path.

An extreme instance of such forward beat is represented in an admirable photograph of a swan rising from the water and published in *The Times*. This shows a very heavy bird performing a very difficult task. As the swan rises higher and its speed increases, so the forward angle decreases until, at full speed, the wing beat is almost, but never quite, vertical.

The essential movements of bird flight have been observed and tabulated in great detail by Prof. E. J. Marey in "Le Vol des Oiseaux."

My invention makes no provision, during flight, for an *upstroke* of the wing, meaning by " stroke " a muscularly actuated movement.

The apparent upstroke in bird flight is, I believe, an actual fall of the body between the air supported wings, *a fall from an ascending path.*

I suppose that the whole of a bird's wing acts as an aerofoil and that the whole of it acts as a propeller, but I think that the part near the body acts more as an aerofoil than as a propeller, and that the extremity of the wing, which I will call the *blade,*[7] acts chiefly as a propeller.

The first experiment which I contemplate with the full size construction is to build on to the wing spars, *blades* of the greatest propulsive aptitude that I can devise, and to test with these the speed which a man can attain in travelling along the ground.

After that I would build on to the wing spars aerofoils of supporting aptitude, between the blade and the thorax.

It is a matter of common observation that two familiar types of non-rigid aerofoil, the wing and the sail, exhibit opposite tendencies under air pressure. The bird's wing, which by construction is concave on the side intended to receive air pressure, tends to flatten out under such pressure; a sail, on the other hand, however taut it may be hauled, tends to belly out under the pressure of the air, becoming concave on the windward side.

A choice between these two types is available to the inventor of a non-rigid wing.

There appears to be the possibility of an intermediate type, the sail with pliant ribs, exemplified perhaps by the Chinese junk and the wing of the bat.

For the *blade* of my experimental wing, I would choose the bird's wing type. This I hope to construct by superposing thin plates of cellon either flat or cambered.

For the part next to the thorax, I hope that a true sail type will suffice. That should save weight. Between the blade and the sail there may be opportunity for the bat's wing type.

But these things must be determined as the game develops.

---

[7] The part, which in the artificial wing I call the blade, is the part composed, in the natural wing, of all the primary and some of the secondary feathers. In so calling it, I adopt the metaphor implied in the ornithologist's term " *remiger* " translating it back into English. I learn from Marey (page 71) that the part composed of the primary feathers is, in French, called " *le fouet,*" by which I understand " the lash."

PROCEEDINGS

A Joint Meeting of the Institution of the Rubber Industry and the Royal Aeronautical Society was held in the rooms of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, October 27th, 1932, when a paper on "Aeroplane Covers and Wheels," by Mr. F. Fellowes, F.I.R.I., was read and discussed.

Major R. H. Mayo, O.B.E., M.A., A.M.Inst.C.E., F.R.Ae.S., presided.

The CHAIRMAN: This was the first joint meeting of the two bodies and marked an important step towards bringing about closer technical co-operation between the rubber industry and the aeronautical industry. He hoped and believed that it would be followed by further joint meetings in the future. He personally considered that the aeronautical industry owed a great debt of gratitude to the rubber industry. The rubber and wheel industries had had to shoulder a heavy burden in developing aircraft wheels and tyres to their present highly efficient state. The business had not been of a very profitable nature, because an enormous amount of experimental development had been required in relation to the volume of business available, but the rubber and wheel industries had never flinched in their efforts to meet the exacting demands of the aeronautical industry. He felt sure the aeronautical section of the audience would agree that those demands had been met with remarkable success. He also felt sure that view would be strengthened by listening to Mr. Fellowes' paper.

It was now nearly nineteen years since Mr. Fellowes had joined the Dunlop Company, having previously acquired all-round experience in electrical and general engineering. While with the Dunlop Company he had been responsible for the design and construction of tyres of all types, including the first aero wheel tyres made by the Dunlop Company. His present appointment as the company's technical superintendent for London and S.E. England kept him constantly in touch with the problems and requirements of the aircraft industry.

Mr. FELLOWES then presented his paper.

AEROPLANE COVERS AND WHEELS

BY

F. FELLOWES, F.I.R.I.

It is not the author's intention to give a résumé of the history of aeroplane covers and wheels, but rather to draw attention to the more modern types of equipment and to show, to some extent, their comparative values.

Aeroplane tyre equipment is tending to develop along similar lines to that of motor car and commercial vehicle tyres, which for a long period "existed" on high pressure B.E. tyres, gradually changing to the high pressure wired type, and finally, to-day, all cars are equipped with low pressure tyres, and a large percentage of commercial vehicles are also on this equipment; while the extra low pressure tyres are in evidence to a lesser extent. What the author would term the "modern aeroplane tyre equipment" may be divided into three classes as shown under the heading "Landing Wheel Tyres."

Landing Wheel Tyres

General Description and Classification.

1. A high pressure range.
2. A low pressure range.
3. An extra low pressure range.

The first consisting of a tyre section designed to carry suitable loads at inflation pressures of between 50 and 60lbs. per square inch; the second range to suit inflation pressures from 20 to 35lbs. per square inch; while the extra low pressure range is designed for an inflation of 10 to 20 lbs. per square inch. The extra low pressure tyre is also known under other designations—such as wheel-less, air-wheel, and doughnut tyres, while the low pressure is also known as the intermediate type.

Fig. 1 shows examples of the three types, superimposed on a common axle line, and Fig. 2 on a common base line.

Taking representative sizes for the same load-carrying capacity from each range, *i.e.*, 7in.-19in. high pressure, 9.50-12 low pressure, and 13.00-6½ extra low

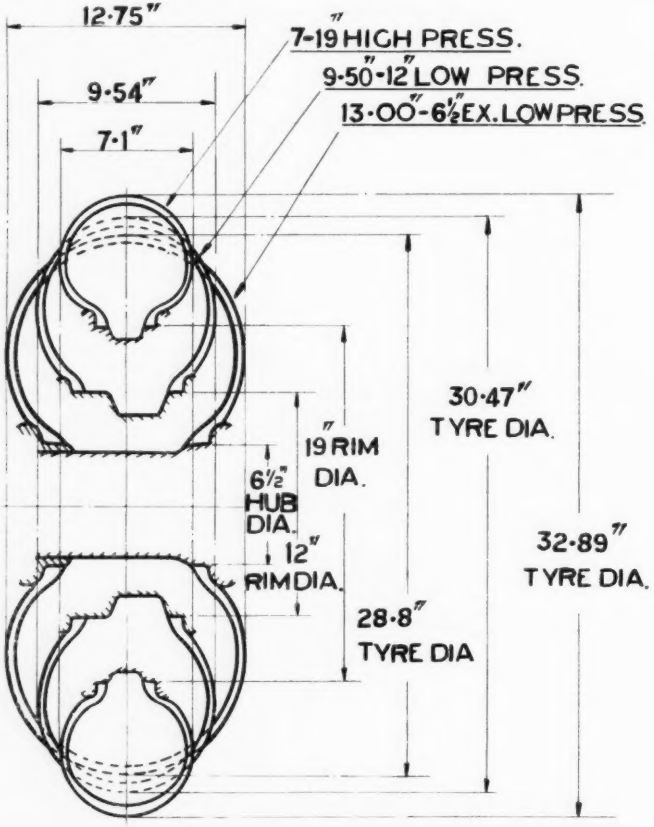


FIG. 1.

Diagram of inflated shapes on common centre.

pressure, each taking a load of 3,000lbs. per tyre, it will be seen that the cross-sectional increase of the low pressure tyre over the high pressure is 34 per cent., while the extra low pressure equals 79.5 per cent. over the high pressure. It will be noted that as the cross section increases, the diameter decreases.

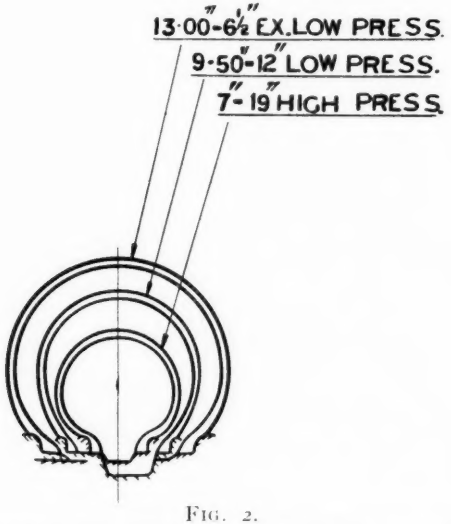


FIG. 2.

Common rim base diagram of inflated sections.

Oversizing

Where the low pressure equipment is in use, and for special ground surface conditions a still lower pressure is desirable, by fitting a suitable over-size tyre to the low pressure type wheel an extra low pressure equipment is provided—without the expense of axle and hub redesign.

Design Characteristics

Fig. 3 shows that the tyre construction of the three types is substantially the same, each being of the wired-edge design.

With regard to casing strengths, the 7in. high and 9.50 low pressure casings each have six plies, or layers, of cord; while the 13.00 extra low pressure has eight plies of lighter material. Other comparative sizes in each range may have from four to sixteen plies, according to size and type. (The 16in. high pressure tyres fitted to the Beardmore reflexible aeroplane had 16 plies.) It is reasonable to assume that the low pressure and extra low pressure tyres, owing to their reduced inflation pressures, may be of lighter construction than high pressures. While this is possible, and in some instances is so, the author holds the view that in the interest of safety, freedom from trouble and ultimate economy on tyre cost, slight additional weight in the form of heavier construction is well warranted.

It has been found in practice overseas, and in the East more particularly, that an additional two plies in a cover have more than proved their value as a guard against casing fracture, or concussion burst and deflations, following punctures by camel thorn.

The total thickness of walls on the 7in. high pressure and 9.50 low pressure is approximately 6mm., and the 13.00 extra low pressure 7.5mm., with crown thicknesses of 10mm. and 10.5mm. respectively.

It will be appreciated that the lower the inflation pressure, the more readily the cover will absorb obstacles without damage to the casing fabric, and in this connection Fig. 3A shows the effect of pressure reduction and also of increasing the number of fabric plies in a 6in. high pressure cover from four to six.

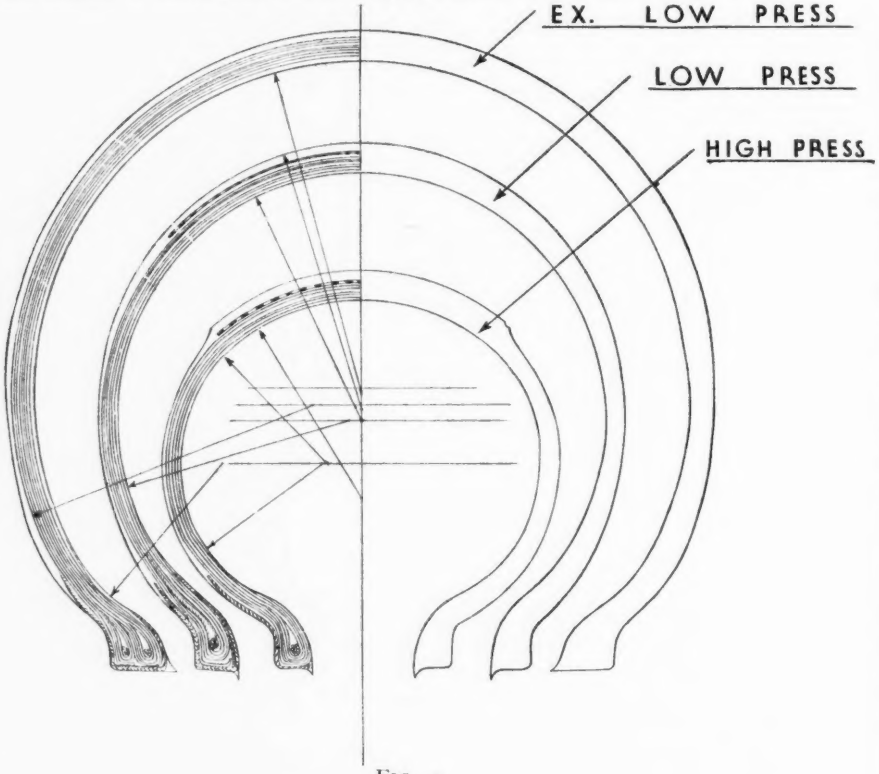


FIG. 3.

Diagrams of construction.

High pressure, low pressure and extra low pressure aero tyres.

Casing strength is not wholly dependent on the number of cord plies. Other factors arise—such as individual cord or thread strength, number of threads per inch, the angle at which threads cross each other, etc. However, details of this nature provide ample material for a future lecture.

With regard to tyre deflection under static load, the general average is 33 per cent., measured from the crown of cover to top of rim flange, compared with a motor car tyre giving an average of 18 per cent. The average safety factor in an aeroplane tyre is between four and five.

Tread Pattern

In this country, and on the Continent, aeroplane covers are usually of the

plain or smooth tread type, while in America many tyres are used having a non-skid tread design.

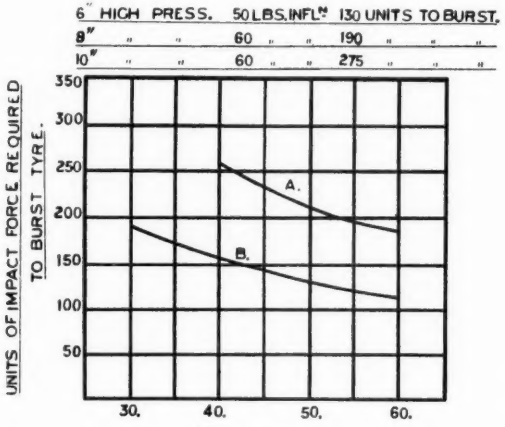


FIG. 3A.

Inflation pressure.

A. 6" high pressure heavy construction.

B. 6" high pressure std. construction.

Graph of impact tests.

Comparative Sizes and Weights

Fig. 4 gives a comparison of tyre sizes and weights. I have shown a picture of size relationship of the three types, and will again make further reference under wind resistance or drag at a later stage.

COMPARISON OF DUNLOP H.P., L.P. & EX. L.P. AERO TYRES.

Size.	Inflated dia.	Inflated width.	Weight of Cover, Tube and Fairing.	Weight of Wheel, Brake, Drum, Plain Brg. type.	Total weight. Cover, Tube, Wheel or Hub.
7"-19" H.P.	32.89"	7.1"	24lb. 6oz.	28lb. 6oz.	52lb. 12oz.
9.50"-12" L.P.	30.47"	9.54"	28lb. 11oz.	17lb.	45lb. 11oz.
13.00"-6½" Ex. L.P.	28.8"	12.75"	32lb. 10oz.	14lb.	46lb. 10oz.
6"-19" H.P.	31.2"	5.84"	22lb. 10oz.	19lb. 10oz.	42lb. 4oz.
8.50"-10" L.P.	26.5"	8.52"	23lb. 11oz.	12lb. 8oz.	36lb. 3oz.
11.00"-6½" Ex. L.P.	25.66"	10.5"	28lb. 8oz.	13lb. 8oz.	42lb.
4"-19" H.P.	27.5"	4.00"	9lb. 7oz.	18lb. 4oz.	27lb. 11oz.
7.00"-7½" L.P.	19.85"	7.17"	12lb. 9oz.	5lb. 13oz.	18lb. 6oz.
9.00"-5" Ex. L.P.	19.8"	8.62"	12lb. 3oz.	8lb.	20lb. 3oz.

FIG. 4.

Weight.—The bane of aircraft designers! A consideration of the table shows that while on the smaller size covers differences are of minor importance, in the larger sizes the low and extra low pressure range are somewhat heavier than the corresponding high pressure. For example, taking the 7in. high pressure as a basis, the 9.50 low pressure has an increase of approximately 19.5 per cent., and the 13.00 extra low pressure approximately 40 per cent. The figures quoted are for cover, tube and, where used, fairings.

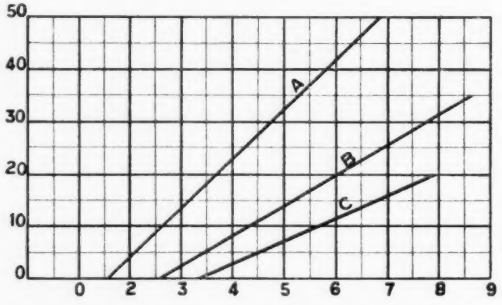
When compared as complete wheels, however, disc type in the case of the high pressures, the 7in.-19in., is approximately 14.5 per cent. heavier than the low pressure tyre and 10 per cent. heavier than the extra low pressure, from which it will be seen that the extra low pressure type is approximately 4 per cent. heavier than the low pressure size.

The weight reduction in favour of the low pressure and extra low pressure types is solely due to difference in wheel or hub dimensions and design.

Static Load-carrying Capacities in Relation to Air Pressures

It will be readily understood that a pneumatic aeroplane cover in itself is incapable of supporting useful loads, it naturally follows that the air within the tube is the load-carrying medium, and in this respect it will be interesting to compare the air volumes in cubic feet, and also the amount of free air taken to support a static load of 3,000lbs. in each type of tyre under review.

While Fig. 5 shows graphically the slight variations in the high, low and the extra low pressure sizes, I think it might be taken that, apart from any minor support the cover may give, the amount of free air required to carry a given load is substantially the same, whether compressed to 50lbs. per square inch or to 10lbs.



A. High pressure ... ... 7″-19″ aero tyre air volume 1.56 cu. ft.
B. Low pressure ... ... 9.50″-12″ ,, ,, 2.55 ,,
C. Extra low pressure ... 13.00″-6½″ ,, ,, 3.32 ,,

FIG. 5.

Graph of variation in amount of free air in tyres.

Contact Areas

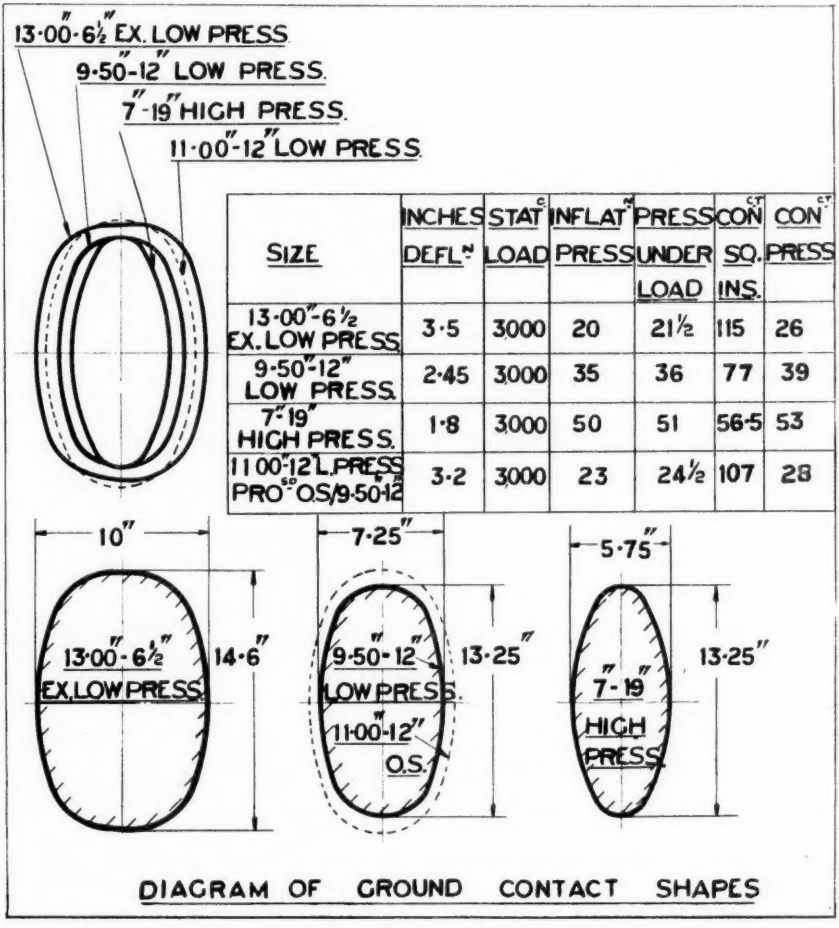
The area of tyre contact with the ground is of vital importance in many respects. Firstly, on the area depends the intensity of pressure. Secondly, on the intensity of pressure, in lbs. per square inch, largely depends the landing "shock" forces transmitted to the undercarriage and ultimately through the aircraft itself. Furthermore, on the supporting area of the tyre, operating over soft surface landing grounds, frequently depends whether or not an aeroplane becomes "bogged."

From the foregoing it will be readily understood that the size of tyre, in relation to the inflation pressures used, determines very largely the area of ground contact. The larger the tyre cross section and the lower the inflation pressure, the bigger the area, and, consequently, the smaller intensity of pressure.

I have referred to aerodrome or landing ground surfaces. Fortunately, in this country we are not troubled with sandy or swampy surfaces to the same

extent as overseas—particularly in the East, where aeroplanes frequently sink up to the axles in sand, or, during the monsoon periods, in mud.

In this connection it will be of interest to compare the intensity of pressure of nature's desert transport, *i.e.*, the camel. While, naturally, camels vary in size, weight and carried loads, I think it would be safe to say that the pressure intensity of a camel's foot varies between 9 and 19lbs. per square inch, with an



SIZE	INCHES DEFL.N	STAT.C LOAD	INFLAT.N PRESS	PRESS UNDER LOAD	CON.CT SQ. INS.	CON.CT PRESS
13·00-6½ EX. LOW PRESS.	3·5	3000	20	21½	115	26
9·50-12 LOW PRESS.	2·45	3000	35	36	77	39
7-19 HIGH PRESS.	1·8	3000	50	51	56·5	53
11·00-12 L. PRESS PRO.SD O.S./9·50-12	3·2	3000	23	24½	107	28

FIG. 6.

Diagram of ground contact shapes.

average of 14/15lbs. Assuming that, say, 15lbs. per square inch will not disturb the surface of the sand unduly, then we may also assume that a similar pressure intensity would be reasonably suitable for aeroplane tyre contact.

An examination of the contact diagram Fig. 6 will show the comparative areas and pressure intensities of the three types of tyres under review, from which

it will be seen that a much larger section tyre, or greatly reduced inflation, would be necessary to equal the camel's foot pressure.

I think we may say that the foregoing remarks equally apply to swampy surface conditions.

Coefficient of Friction

With the more prevalent use of brakes, a few figures on coefficient of friction between the tyre and landing ground surface will be of interest. It will be appreciated that with the very varied conditions of aerodrome surfaces, only general average figures can be quoted.

Concrete surface	dry .7	wet, but clean .7	muddy .55
Tarmacadam ,, ...	,, .7	wet .5	
Hard base, with light top dressing of sand ...	,, .65	,, .5	
Steel	,, .6	,, .3	

Useful friction data on grass landing surfaces is known, but difficult to obtain owing to the varied nature of the ground; the dry average would be .5, while when wet it may drop below .1.

With regard to aircraft carrier landing docks, with a wet highly-polished steel surface the coefficient of friction may be as low as .1; while on smooth ice it may be even less.

SIZE	LOAD LBS.	INFL" PRESS LBS.⁰"	EFF. RAD	HEIGHT OF TYRE SEC. ABOVE RIM FLANGE.	EFF. RAD. DEFL° TYRE	DROP IN EFF. RAD. OF DEFL° TYRE.
13·00"-6½" EX. LOW PRESS.	3,000	20	10·9	10·15	5·4	5·5
9·50"-12" LOW PRESS.	3,000	35	12·78	8·44	7·78	5
7"-19" HIGH PRESS.	3,000	50	14·64	6·03	11·28	3·36
11·00"-6½" EX. LOW PRESS.	2,200	20	9·83	8·58	5·4	4·43
8·50"-10" LOW PRESS.	2,200	32	11·05	7·55	6·78	4·27
6"-19" HIGH PRESS.	2,200	47	13·8	5·27	11	2·8
9·00"-5" EX. LOW PRESS.	1,400	20	7·65	6·4	4·5	3·25
7·00"-7½" LOW PRESS.	1,400	33	8·38	5·52	5·38	3
4"-19" HIGH PRESS.	1,400	49	12·45	3·5	11	1·45

FIG. 7.

Section height with effect of deflation on effective radius.

When dealing with tyre skidding, or slipping, the coefficient has a very indefinite value, as the presence of water or a thin film of mud covering hard ground will frequently upset known characteristics, but as an all-round useful figure .3 would not be far out.

Landing Surfaces

While I have previously referred to landing or ground surfaces, there is another aspect to be considered—that of sectional size of tyre in relation to wheel or hub diameter. Where rough or undulating surfaces are prevalent, the question of diameter and drop following tyre deflation becomes important. The smaller the diameter the greater the drop, the more liable for an aircraft to overturn.

Figs. 7 and 8 show dimensional data and diagram angle of approach over an obstacle or ground undulation respectively, from which it will be seen that, in this respect, the extra low pressure equipment is at a disadvantage compared with the other two types.

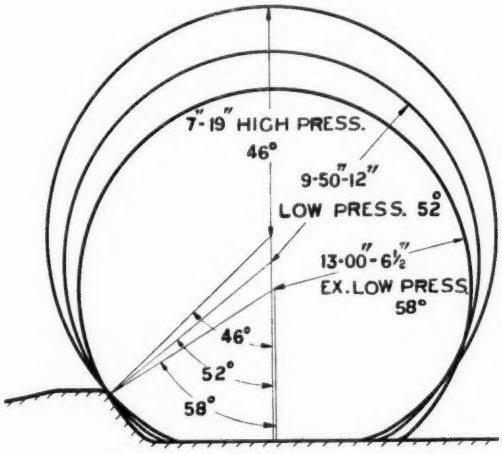


FIG. 8.

Diagram showing variations in angle of approach on rough landing.

Angle of Stability

Fig. 8A gives a picture of tyre sectional width to rim width of the three types of equipment, from which may be judged, to some extent, the angle of stability; or, in other words, freedom from roll. The extra low pressure tyre would appear to hold the advantage, but this may be offset by the possibility of roll due to flabbiness of tyre casing and the very low pressure. I would say that a slight increase in air pressure will more than counteract any advantage in rim width.

Aerodynamic Properties

The aerodynamic drag of wheels and tyres is, next to weight, probably one of the most important points in undercarriage design, and a comparison of the three types of equipment will be of value.

In this respect I cannot do better than quote extracts and show diagrams from investigations made by Mr. George H. Dowty.

The wheel sizes now under consideration differ in some respects from those previously under review, but will serve the purpose for which they are intended.

The wheel sizes, for which tests have been conducted, are as follows:—

High pressure ...	3in. for 17in.	Overall dimensions	3in. × 25in.
	4in. for 19in.		4in. × 27.5in.
	8in. for 19in.		8in. × 35.5in.
Low pressure ...	7.00in. for 7½in.	,, ,,	7in. × 19in.
Extra low pressure	7.00in. × 4½in.	,, ,,	7in. × 16.5in.
	10.00in. × 5in.		10in. × 20.5in.
	13.00in. × 6½in.		13in. × 28.5in.

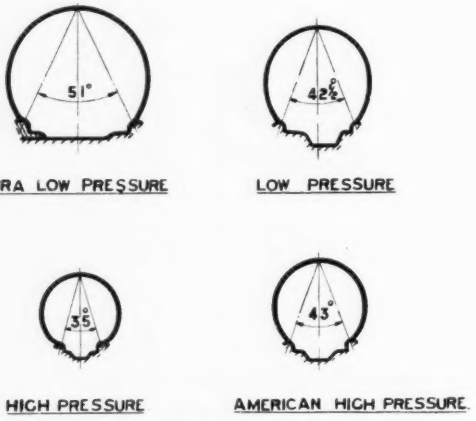


FIG. 8A.

Tyre and rim sections with angle of stability.

Comparisons can only be made between wheels of similar capacity. Taking the low pressure tyre at inflation pressures of 20 and 30lbs. per sq. in., two cases can be examined—for tyres with rated capacities of 1,000 and 1,500lbs. static load. This permits direct comparison between 4 × 19 high pressure, 7.00-7½ low pressure, and 10.00 × 5 extra low pressure for one case and 3 × 17 high pressure, 7.00 × 7½ low pressure and 9.00 × 5 extra low pressure for the other. There was no 9.00 × 5 Dunlop extra low pressure tyre available, and the figures for Goodyear equipment have been used in this instance.

The resulting decrease in drag of low pressure and extra low pressure tyres will be shown on Figs. 9 and 10. The saving is very great and this is undoubtedly one of the strongest claims which can be advanced for this type of wheel.

The aerodynamic resistance of these wheels can be plotted directly from the wind tunnel test, since full-sized tyres and wheels were employed and the value of *VL* is such that no correction for scale offset is required.

The comparative test on a 7.00 × 7½ low pressure tyre, with and without side covers, or fairings, have been analysed (see Fig. 11). This wheel and tyre combination shows little advantage from this refinement. The small re-entrant angle of this unit, however, does not afford a good example for a test of this description. Nevertheless, it will be observed that a cross section of approximately 5 per cent. of the total frontal area is covered by the shields and in so doing the total drag is reduced by approximately 5 per cent. If a wheel and tyre combination was tested in which the tyre cross section greatly exceeded the maximum width of rim, considerable saving should be effected. It would appear reasonable

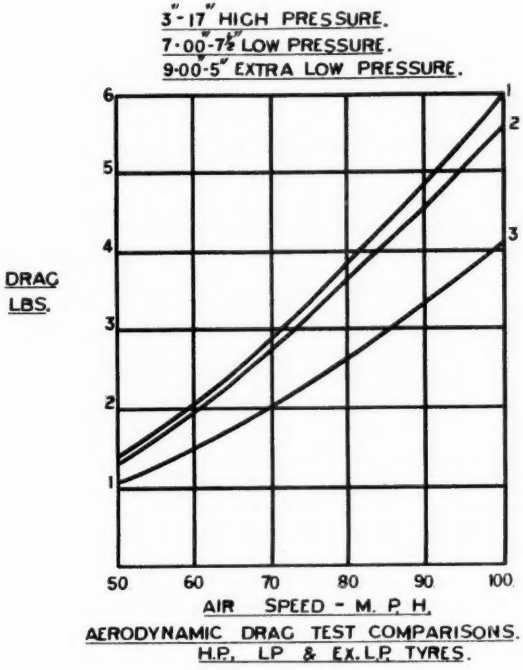

3"-17" HIGH PRESSURE.
7·00-7½" LOW PRESSURE.
9·00-5" EXTRA LOW PRESSURE.
DRAG LBS.
6
5
4
3
2
1
1
2
3
50
60
70
80
90
100
AIR SPEED - M. P. H.
AERODYNAMIC DRAG TEST COMPARISONS.
H.P., LP & EX.L.P. TYRES.

FIG. 9.

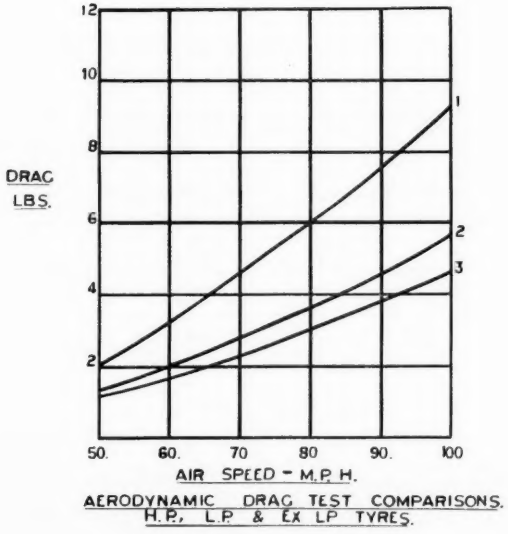
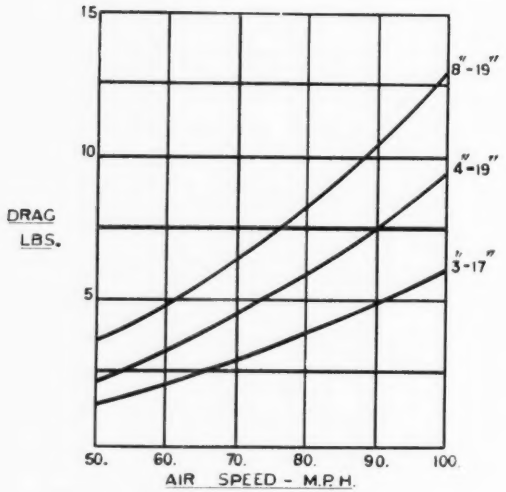

DRAG LBS.
12
10
8
6
4
2
1
2
3
50.
60.
70
80
90.
100
AIR SPEED - M.P.H.
AERODYNAMIC DRAG TEST COMPARISONS.
H.P., L.P. & EX LP TYRES.

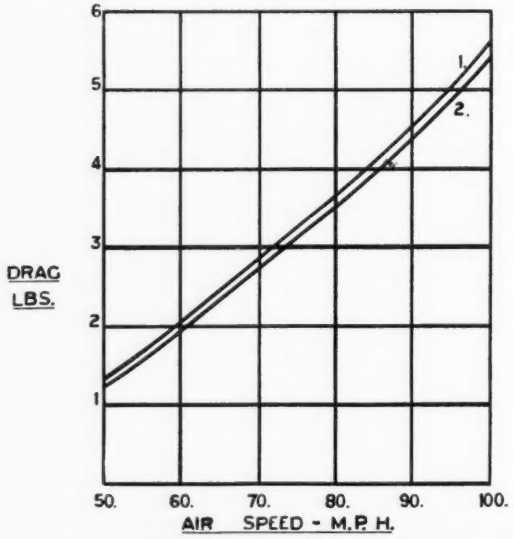
FIG. 10.



AERODYNAMIC DRAG TEST.
HIGH PRESSURE TYRES

FIG. 11.

1. 7·00"-7½" LOW PRESSURE.
2. 7·00"-7½" LOW PRESSURE WITH FAIRING FROM TREAD TO HUB.



AERODYNAMIC DRAG TEST.
LOW PRESSURE TYRES.

FIG. 12.

to assume a reduction on the following basis: True cross-sectional area; frontal area with tyre to hub fairings.

Wheels having a high ratio should show proportionately large savings. This fact is borne out by tests recorded in this country and abroad.

In the foregoing the author has confined his remarks to wheel and cover fairings of the more common types in use. In this connection the Dunlop Company have recently evolved a new type of fairing consisting of a sponge rubber anulus, of sectional shape to suit the dip or recess at the tyre rim, the anulus being supported against the cover by a light metal disc. Wind tunnel tests on this type of fairing have been carried out, and results have proven highly satisfactory.

Assuming an aeroplane with an engine developing 150 b.h.p., equivalent to a thrust horse-power of 120, total machine weight 2,800lbs.; maximum top speed 120 m.p.h.

The change in wheel equipment from 4×19 high pressure tyres to $7.00 \times 7\frac{1}{2}$ low pressure will result in a saving of 11-14lbs. drag at maximum speed. Interference effect has been added to the parasitic wheel drag. This is equivalent to a saving of 5-7h.p., or 4-6 per cent. of the thrust horse-power. This will enable the machine to develop a higher maximum speed or to cruise more economically (*i.e.*, with a lower expenditure of power).

Graphical results of wind channel tests are illustrated on Figs. 9 to 14a inclusive:—

Fig. 9.—3×17 high pressure, $7.00 \times 7\frac{1}{2}$ low pressure, 9.00×5 extra low pressure.

Fig. 10.—4×19 high pressure, $7.00 \times 7\frac{1}{2}$ low pressure, 10.00×5 extra low pressure.

Fig. 11.—$7.00 \times 7\frac{1}{2}$ low pressure with and without fairings.

Fig. 12.—High pressures, 8×19, 4×19, 3×17.

Fig. 13.—Dunlop extra low pressure.

Fig. 14.—Goodyear extra low pressure.

Fig. 14A.—High pressure, low pressure and extra low pressure, superimposed diagram of frontal area.

Before leaving the wind tunnel test matter, I should mention that other developments, in the form of combination fairings which include undercarriage strut and axle joints, enclosing the wheel and tyre in spats, mudguards, etc., have also been tested. Report and Memoranda No. 1479, issued by the Aeronautical Research Committee, is a very comprehensive survey of this subject. The results shown in this report confirm substantially the investigations carried out by Mr. Dowty.

Extracts of conclusions from this report will be of interest.

Range of Investigation

The unit taken for test was half the undercarriage of an interceptor flighter, less oleo; that is to say, one wheel, a length of axle, two strut ends, and the connecting joint. The following conclusions were reached.

The drag of the complete undercarriage is estimated to be 16in. at $V = 100$ft./sec. Changes in this drag are given below:—

(*a*) 3 to 4lbs. may be saved by fairing the axle-strut joint.
(*b*) $7\frac{1}{4}$lbs. may be saved by enclosing the wheel in a spat.
(*c*) The addition of a tailfairing does not improve the drag.
(*d*) The mudguard fitted over the wheel increased the drag by $3\frac{3}{4}$lbs.
(*e*) $6\frac{3}{4}$lbs. may be saved by fairing the wheel and fairing the axle-strut joint.

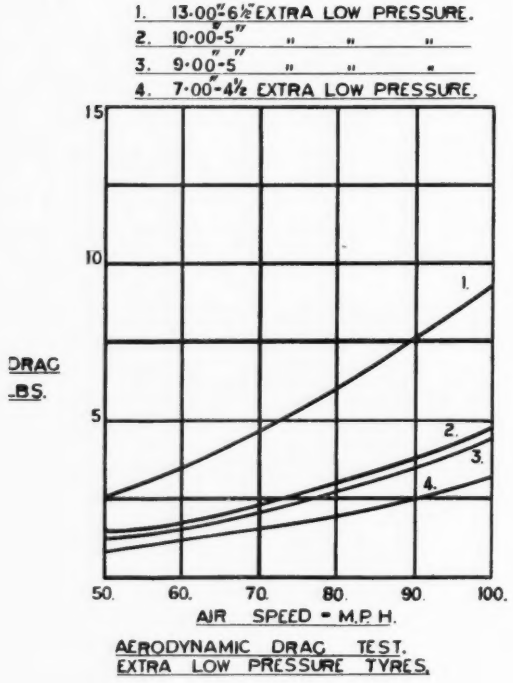

1. 13·00"-6½" EXTRA LOW PRESSURE.
2. 10·00-5" " " "
3. 9·00"-5" " " "
4. 7·00"-4½ EXTRA LOW PRESSURE.
15
10
5
DRAG LBS.
1.
2.
3.
4.
50. 60. 70. 80. 90. 100.
AIR SPEED - M.P.H.
AERODYNAMIC DRAG TEST.
EXTRA LOW PRESSURE TYRES.

FIG. 13.

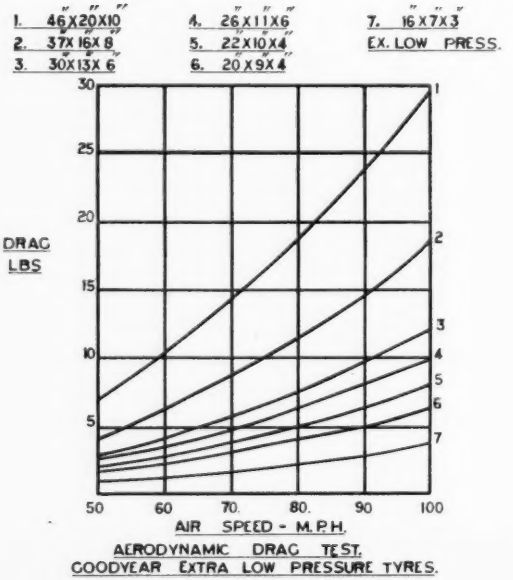

1. 46"X20"X10"
2. 37"X16"X8"
3. 30"X13"X6"
4. 26"X11"X6"
5. 22"X10"X4"
6. 20"X9"X4"
7. 16"X7"X3"
EX. LOW PRESS.
30
25
20
15
10
5
DRAG LBS
1
2
3
4
5
6
7
50 60 70. 80. 90 100
AIR SPEED - M.P.H.
AERODYNAMIC DRAG TEST.
GOODYEAR EXTRA LOW PRESSURE TYRES.

FIG. 14.

(*f*) and (*g*) The fabric-covered or faired wire wheel, and the disc wheel of comparable size, have the same drag.

High pressure wheel, 26in. × 5in., 3.75lb. per sq. ft. frontal area.
Low pressure wheel, 13.00in. × 6½in., 2.79lb. ,, ,,
,, ,, 10.00in. × 5in., 2.52lb. ,, ,,

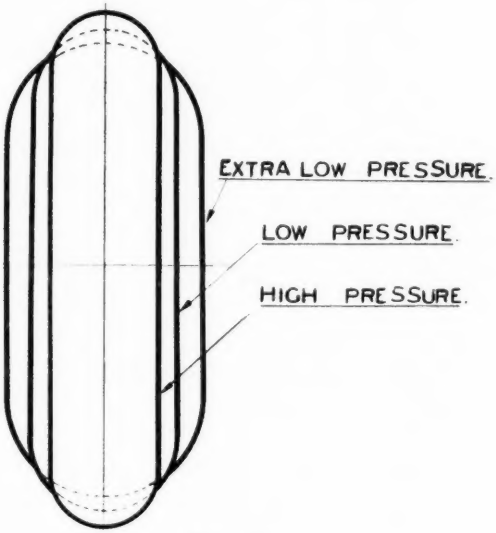


FIG. 14A.
Inflated shapes of tyres,
showing area presented in wind tunnel test.

The drag of axle or struts, with service fairing, was about 1¼lb. per sq. ft. of frontal area. The increase of speed corresponding to 7¼lb. drag saving by using a spat would be about 4½ m.p.h. on 200 m.p.h.

The foregoing shows the advantage of fairings.

In connection with the weight of wheels, two corrections are necessary for low pressure and extra low pressure tyres if a fair comparison is made. The lower pressure tyres being of larger width than the high pressure type imposes an increased bending moment on the axle which necessitates an axle of larger diameter or increased wall thickness. The former method will increase the axle resistance, and the latter put up the axle weight. The other correction is due to the smaller wheel diameter, and this feature entails the lengthening of the shock absorber struts and other structural members of one half the difference between the effective diameters of the high and low pressure tyres. This is necessary, of course, to preserve the same airscrew ground clearance. The increased resistance will be mitigated in whole, or in part, by the smaller size wheel and by virtue of the wheel mass being concentrated at a more remote position in relation to the aeroplane body. This will certainly reduce the aerodynamic losses due to the mutual interference effect of the wheels with the air flow about the body.

It is well known that the aerodynamic drag of individual components is considerably modified when assembled to a complete machine. This is due to the mutual interference of adjacent parts. In some cases the undercarriage, when

assembled to a machine, has been found to be twice that of the sum of the individual parts.

It is patent, therefore, that a check should be made, testing an aircraft model with high and low pressure tyres. This will establish the net drag reduction, and it is possible that the saving will be considerably greater than that given by the tests on the wheel units alone. (See Figs. 15 and 16, showing wheel track comparisons and types of fairings respectively.)

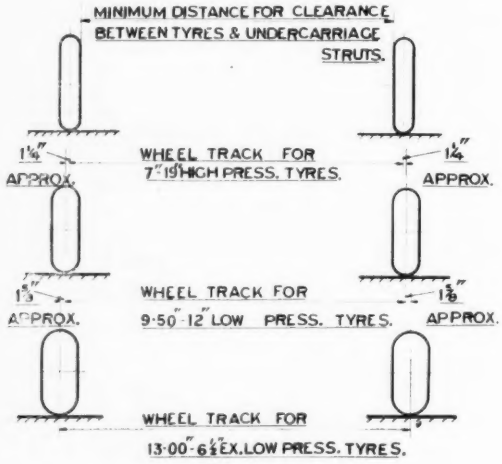

MINIMUM DISTANCE FOR CLEARANCE BETWEEN TYRES & UNDERCARRIAGE STRUTS.
1¼" APPROX.
WHEEL TRACK FOR 7"-19" HIGH PRESS. TYRES.
1¼" APPROX.
1⅝" APPROX.
WHEEL TRACK FOR 9·50"-12" LOW PRESS. TYRES.
1⅝" APPROX.
WHEEL TRACK FOR 13·00"-6½" EX. LOW PRESS. TYRES.

FIG. 15.

Diagram of varying wheel tracks.

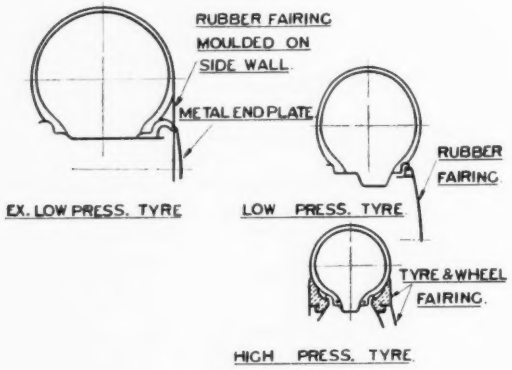


FIG. 16.

Diagram showing method of fairing tyres and wheels.

The combined advantages of weight and drag must inevitably lead to the increased use of the low and extra low pressure tyres.

Energy Absorption

Fig. 17 shows comparative tyre energy deflection value from which it will

be obvious that the low and extra low pressure equipment have a marked advantage.

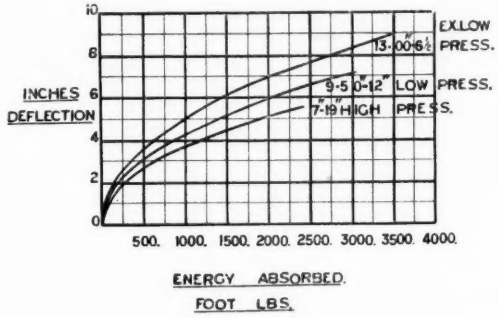


FIG. 17.

Graph of energy-deflection curves.

Tail Wheel Tyres

With braked landing wheel, the pneumatic tyre tail wheel is becoming more popular, the advantages of which will be obvious. In this connection, the extra low pressure tyre with the small overall diameter will have an advantage over other types.

Wheels

It is well known that for many years the standard aeroplane wheel has been of the wire type, and it is only comparatively recently that other types of wheels have become popular and are gradually replacing the wire type.

It should be stated here that the wire wheel has been limited to the high pressure tyre equipment and that any comparisons will, of necessity, be confined to this range.

While the wire wheel has given excellent service in the past, when compared with the disc wheel, it has been found lacking in many respects. The disc wheel has a much cleaner profile, thereby reducing wind resistance or drag. The thought will naturally arise, does not the faired type wire wheel also reduce drag? As shown already, fairings have a marked advantage, in many instances, but with the canvas fairings, used with wire wheels, frequently becoming partly or wholly detached, the general performance is in favour of the unfaired disc wheel. Reference has already been made to the use of fairings on low pressure and extra low pressure type tyre wheels.

Strength, Weights and General Design

For high pressure tyres the disc wheel, owing to its design, permitting the use of materials of low specific gravity, is considerably stronger and at the same time lighter than its equivalent wire wheel. A comparison will show the advantage to be gained.

A 12in. for 35 Dunlop wire wheel carrying a maximum useful load of 9,000lbs. weighs 74lbs. and has a failing load of 39,000lbs., while the same size Dunlop disc wheel weighs only 67lbs. and has a failing load of 50,000lbs. Thus, the wire wheel is 10.5 per cent. heavier and is approximately 28 per cent. weaker. Smaller size comparisons may be taken as more or less in proportion.

All wheels must conform to the Air Ministry formula for failing load, *i.e.*, normal failing load=65 D.B., where " D " is the outside diameter of tyre and " B " is the breadth or width. As an example, taking a 7in. for 19

high pressure tyre, measuring 33in. diameter and 7in. breadth, we have 65 D.B. = 65 × 33 × 7 = 15,015lbs. failing load. As the 7in. tyre carries a maximum load of 3,000lbs. it will be seen to have a safety factor of five.

Dealing with the more modern type wheels, or hubs in the case of the extra low pressure type, Fig. 18 shows an arrangement of a typical high pressure type wheel, complete with brake drum, the design of which, it will be noted, consists of a main body and hub in the form of a casting, secured to the rim by means of two discs, the one extending from the hub while the other is attached to the brake drum housing. With this construction a considerable saving in weight is obtained by using elektron for the main body member, while for the rim and discs duralumin is used.

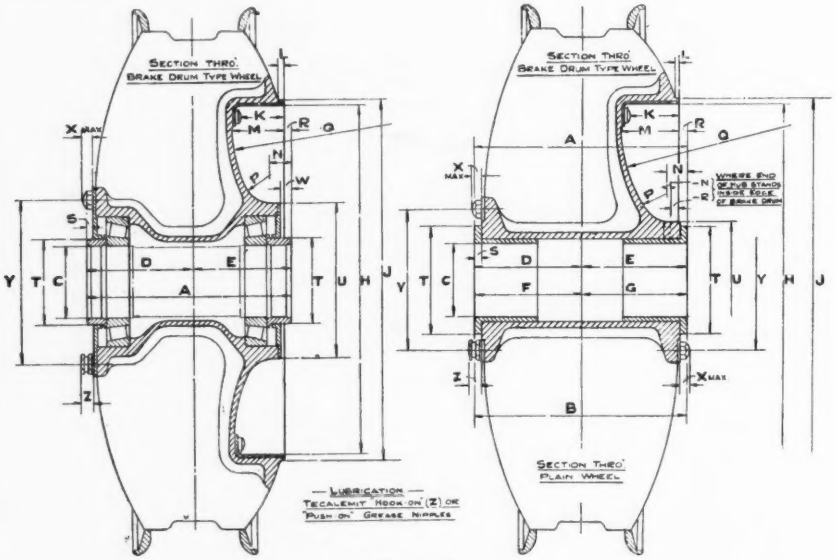


FIG. 18.

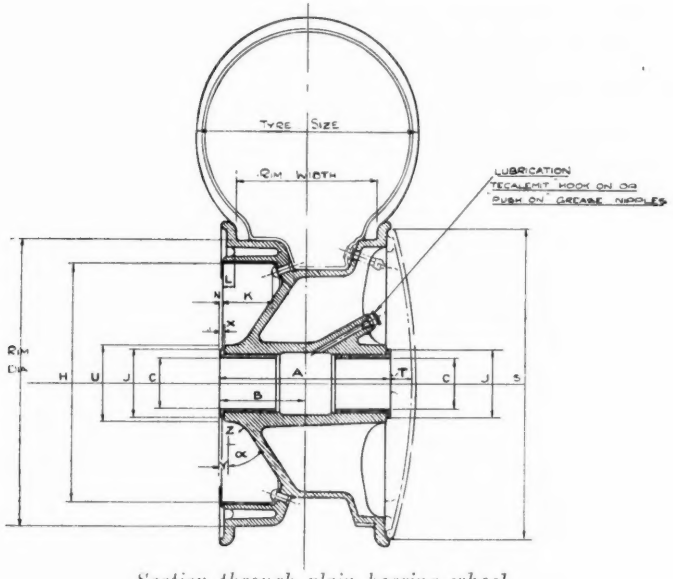
The low pressure type wheel is usually a one-piece elektron casting, incorporating a well base rim. When an end cover plate or fairing is used this may consist of a light metal alloy or, as frequently used on the smaller sizes, a hard rubber material (see Fig. 19).

Fig. 20.—The hub, it cannot be termed a wheel, for the extra low pressure tyre, consists of two elektron castings, one the main body incorporating one tyre bead supporting flange and the other is the detachable flange which, when removed, permits the cover to be fitted or withdrawn.

One of the difficulties experienced with alloy wheels is that of corrosion, and it has been found necessary to protect the surface with cellulose enamels. However, in this respect, other materials are under test, such as M.G.7 for rims and discs, and for marine aircraft hiduminium casing in place of elektron. For amphibian aircraft, stainless steel is under consideration. Stainless steel is used for studs and nuts in all Dunlop wheels.

Brakes

There is ample material to provide a paper on this subject alone. Mr. R. Waring Brown gave a comprehensive survey on aeroplane braking systems only



Section through plain bearing wheel.

FIG. 19.

last year. It is not, therefore, the author's intention to deal with this at any length, but rather to draw attention to the respective possible accommodation for brakes in the three different types of wheels under review.

From the wheel designs which have been shown, it will be observed that while the high pressure and low pressure type wheels have ample room for brakes, the extra low pressure hub is somewhat limited, particularly in diameter, although the possible width is three or four times that of the standard type brakes. While brakes have been fitted to this type of hub, the author is doubtful if their efficiency is equal to that of the larger diameter more orthodox type.

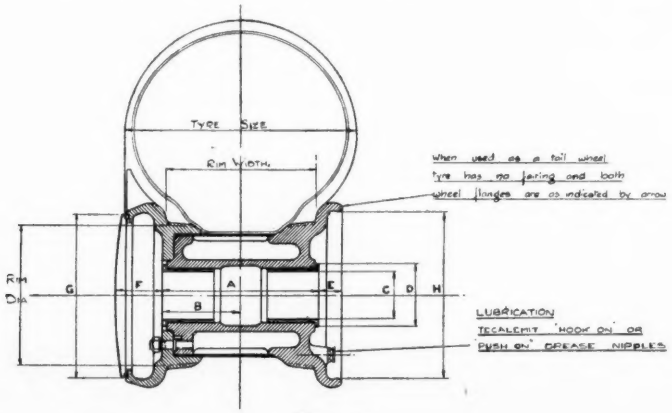


FIG. 20.

In passing, it should be mentioned that the latest development in brakes is one by the Dunlop Rubber Company, operating on the pneumatic system, a big advantage of which is that of weight reduction.

Had time permitted, many other phases of tyre and wheel equipment could have been dealt with and future papers would have ample material in dealing with tyre manufacture, wheel testing and the latest braking systems.

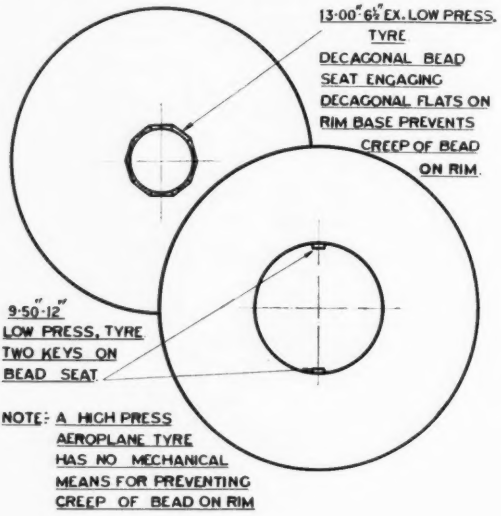

13·00"6½" EX. LOW PRESS. TYRE
DECAGONAL BEAD SEAT ENGAGING DECAGONAL FLATS ON RIM BASE PREVENTS CREEP OF BEAD ON RIM.
9·50"-12" LOW PRESS. TYRE TWO KEYS ON BEAD SEAT
NOTE: A HIGH PRESS AEROPLANE TYRE HAS NO MECHANICAL MEANS FOR PREVENTING CREEP OF BEAD ON RIM

FIG. 21.

Diagram showing method of preventing bead creep.

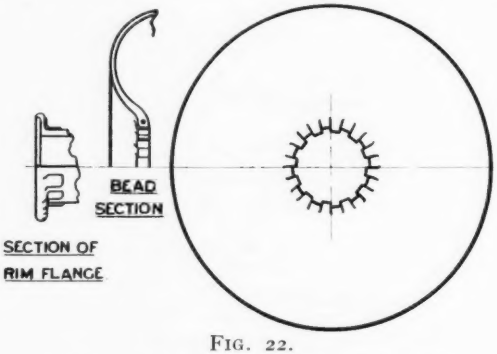


FIG. 22.

Diagram of tyre, bead and rim section (Goodyear extra low pressure).

Fig. 21 shows Dunlop method of preventing creep on extra low pressure tyres.

Fig. 22, Goodyear method of preventing creep on extra low pressure tyres.

In passing, two methods of preventing punctures from camel thorn will be of interest. Fig. 23 shows a type of tube, included in the build up of which is a plastic rubber material, which is intended to act as a self-sealing device around

the puncturing implement, thus preventing the air escaping, while Fig. 24 shows the type of cellular liner interposed between the tube and the crown of the cover, the object being to put as great a distance between the column of air and the ground surface, thereby necessitating a penetrating implement of considerable length before actual penetration of the air tube is made. It will be

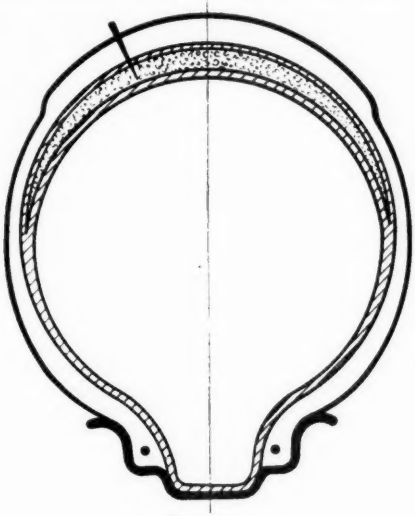


FIG. 23.
Sectional diagram of aero tyre, fitted with "plastic crown" tube.

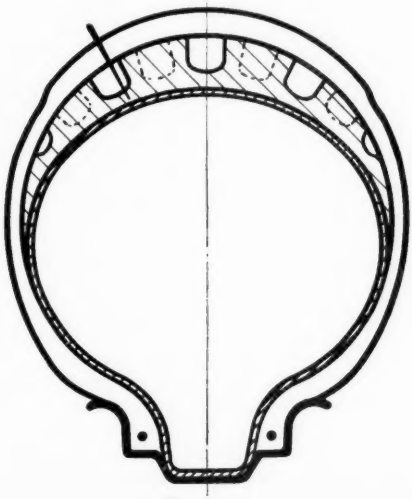


FIG. 24.
Sectional diagram of aero tyre, fitted with cellular liner.

readily understood that the object of making the liner in cellular form is to reduce weight to the minimum.

Except where otherwise stated, the author's subject matter in this paper has been based on products made by the Dunlop Rubber Co., and while there may be slight differences compared with other makes of equipment, substantially they may be taken as representative.

In conclusion, the author is of the opinion that, considering the advantages and disadvantages of the three types of tyres, the low pressure or intermediate range is the most suitable all-round equipment.

Thanks are extended to Mr. George H. Dowty and to others for the valuable data supplied for this paper.

Discussion

The Chairman: When one considered the treatment given to wheels and tyres, it must be admitted that they stood up to that treatment remarkably well; the wheels and tyres were treated more severely than any other part of the aircraft. In the early days of flying, good landings were comparatively rare, a good landing being defined as any landing in which the pilot was not killed outright. Since those days a great deal of improvement had been made, and to-day it might be said that a landing is a good landing if it does not involve the underwriters in a cash payment. He was told that underwriters interested in aviation were on the whole very prosperous, and they must conclude from that that the general standard of landings was now fairly high. Nevertheless, the modern wheel and tyre were stressed to a very much higher degree than the wheel and tyre of the old days, but in spite of that they were much more efficient aerodynamically and of less relative weight. That was due entirely to the efforts of the rubber and wheel industries, and it was clear that the Dunlop Company, with which Mr. Fellowes had been associated, had contributed very largely to the success achieved.

Mr. Dowty: He endorsed the lecturer's remarks on low and medium pressure tyres, and it was his belief that they would entirely replace high pressure equipment within two years.

In addition to the advantages mentioned by Mr. Fellowes, for a given horizontal brake load, there was a smaller torque with low pressure tyres, since the rolling radius was smaller. This feature should permit of a lighter undercarriage structure and smaller loads in the aircraft frame. He regretted that Mr. Fellowes had given no definite figures for the drag of Dunlop wheels fitted with the new sponge rubber fairing. Particulars published in a recently issued report showed that this fairing reduced the drag of an aircraft wheel to a value equal to that of a wheel within a shroud. That being so, it seemed to him that the fitting of shrouds was unnecessary because they not only increased undercarriage maintenance, but were heavy and costly to produce. The shroud also serves the purpose of a mudguard, but he suggested that adequate means could be provided in the shape of a scraper or something of that sort to deal with the mud problem. The undercarriage would be very much simpler if shrouds were not used, and he asked what machines, if any, had been fitted with Dunlop fairings.

Mr. Fellowes: He had not quoted the wind tunnel test results on the sponge rubber fairing because the report and memoranda to which he had referred had only just been issued, and was hardly circulated, so that he did not feel justified in giving too much data from it before it was finally published. Further, his paper was completed before the report was available. However, anyone interested in the subject would find the report (No. 1479) most valuable. The only machine which was fitted with a sponge fairing, within his knowledge, was the Fury. The fitting of the fairing to other types was under consideration. He agreed with Mr. Dowty as to the advantages of faired wheels in place of shrouds.

Mr. BEHARRELL: Commenting upon the lecturer's comparison of the evolution of the aeroplane tyre and the car tyre, they had arrived at a type of car tyre corresponding to the intermediate low pressure. He agreed that in the aeroplane tyre field, as in the car tyre field, it looked as though they would arrive at a compromise. The tendency in car tyres was to revert to the flabbier and softer type, but he believed the movement towards the flabbier tyre would be a very slight one, and that they would not get back to the old type of balloon tyre as fitted to motor cars earlier. There might be a similar movement in regard to the aeroplane tyre, but he believed it would be only in isolated cases, where aeroplanes had to land under extreme conditions, such as in sand and swamps. Otherwise, he was in agreement with the lecturer, although he believed the question of tail wheel fitment was an open one. It had been suggested that the extreme low pressure tyre was suitable for the tail wheel; he ventured to suggest that some indulgence in that direction would still be necessary.

The question of tread patterns was important to manufacturers, as there were so many developments on the way, and he asked for information concerning the requirements of tread on aeroplane tyres, especially in view of the developments in connection with brakes.

Mr. FELLOWES: The tread pattern was a subject which had received a good deal of consideration, but in the view of the manufacturers it was not necessary to have a tread on an aeroplane tyre. He believed that the majority of landing grounds or aerodromes outside America had surfaces of grass, sand, or mud, whereas in America the surfaces were of concrete. For this reason some of the American aeroplanes had tread patterns, and such patterns were reasonably effective on concrete surfaces, but on grassland or swamps they would be useless. The depth of tread would not be more than 5 mm., compared with 10 to 12 mm. on a motor car tyre, the patterns would be filled immediately, so that the tyre surface would really become smooth. Furthermore, the tread patterns would tend to pick up mud and increase the weight, and if there were no mud the wind resistance would be increased by the projections forming the tread pattern.

Mr. HALL (Chief Engineer, Imperial Airways, Limited): Speaking from the users' point of view, he expressed his appreciation of the great amount of work which the tyre trade in general, and particularly the Dunlop Company and Mr. Fellowes, had done in the development of aircraft tyres. He had nothing but admiration for the way in which that equipment stood up to the strenuous usage to which it had been subjected.

Mr. Hall went on to refer to concussion bursts, and said that he was still hoping that tyre manufacturers would be able to protect the users against the most destructive enemy of the tyre, *i.e.*, the stone which caused sudden acute localised deflection of the cover and too often resulted in a burst—sometimes considerably later and almost always without warning. Usually the tyre passed over a stone on the aerodrome without anybody knowing it and later on—sometimes during the night—what was thought to be a perfectly good tyre would burst and be found completely ruined. The tyre manufacturers had already had some success in dealing with this serious trouble, but it was not sufficient and he was still looking forward to further improvement—possibly developed from new lines of thought.

Imperial Airways have not yet gained very much experience with either fairings on the wheels or spats over them, but it was obvious that both would contribute appreciably to reduction of drag. The disadvantages of spats, as he saw them, were the difficulty of preventing them filling with mud and the enclosure of the tyre in such a way that inspection and replacement were retarded.

With regard to treads of the types used on motor cars, he was afraid that they would be worse mud-slingers than the smooth treads now commonly used and would thus add to the risk of damaging the propellers and planes, and in some cases the engines also, unless adequate mudguards were provided. Further, he did not see any reason to expect that treaded tyres would offer any greater

resistance to concussion bursts than smooth ones—on the contrary he thought that the additional weight of rubber on the tread, which is relatively of little use as a safeguard against concussion bursts, might induce designers to reduce the cords in order to save weight. He had no experience of treaded tyres on aircraft, but judged that they do not offer advantages likely to offset the decrease in paying loads which would follow their use.

With regard to intermediate and low pressure tyres, he was of the opinion that they would offer the same advantages on aircraft as they gave on road vehicles, but he did not see eye to eye with those who claimed for them great advantages in getting off from and alighting upon yielding surfaces, because he was of the opinion that pilots who relied upon such claims would, sooner or later, find themselves in real difficulties. As for dispensing with shock absorber legs when low pressure tyres were used, he would just as soon think of dispensing with spring suspension on road vehicles.

With regard to " doughnut " tyres, he found himself in agreement with the lecturer in that this type of wheel increases the risk of the aircraft standing on its nose if the wheels drop into a trench which a larger wheel would have bridged.

Mr. FELLOWES: Discussing concussion bursts, he had on his diagrams shown the value of a reduction in inflation pressure from 60 to 30; it increased the unit of impact required to effect a burst by 50 per cent. On the same diagram he had shown the figures for a tyre having two additional plies, which had given an increased impact of 50 per cent. at the high pressure of 60lbs. per square inch; when the pressure of the tyre was reduced to 30lbs., from 60 to 65 additional units of force would be required to burst the tyre. So that, with a larger section tyre at a lower pressure, the tyre would give to an obstacle as well as to its own load when it came to the ground. The same object could be achieved by increasing the number of plies in the tyre, but that meant additional weight, which was a problem they were all fighting against.

Mr. W. DOUGLAS (Royal Aircraft Establishment): What form of impact test did the author use for measuring the resistance of a tyre concussion? Not very much had been stated in the paper with regard to the relative performances of the three different types of tyre during the landing of an aeroplane, but there were at least two main effects which were of interest. One was the energy absorption contributed by the tyre in bringing the aircraft to rest; the other, which was a little more difficult to treat, was the effect of the semi-sprung weight of the wheel and axle which floats between the pneumatic spring of the tyre below and the upper spring which is usually fitted (in the form of oleo, compression rubber, or something of that nature). It had been suggested sometimes—not usually in this country—that when extra low pressure tyres were fitted it was unnecessary to fit any other form of spring energy absorber in the undercarriage structure. That, of course, had one element of weakness, in that if the tyre were punctured when the aircraft was leaving the ground there was danger of a collapse on landing. It had been demonstrated that, when the extra low pressure tyre was used, even if it were punctured, the atmospheric pressure in the tyre was frequently enough to ensure a safe landing, provided the landing was a good one. But it was interesting to note that if one wished to bring an aeroplane to rest from a given velocity without exceeding a given acceleration (say 5g.), using some form of compound or simple spring with roughly triangular characteristic, one must have a certain vertical distance in which to bring the aircraft to rest. To absorb the kinetic energy due to a vertical velocity of about 10ft. per second, one needed at least $7\frac{1}{2}$ inches of vertical travel for this member with a triangular load deflection characteristic to bring the aircraft to rest without exceeding five times " g." If one relies, therefore, on the tyre alone, one must have a tyre which has $7\frac{1}{2}$ inches of available compression. This means that the smaller sizes of tyre must be supplemented by some additional form of springing.

Another point of interest was the force necessary to accelerate the wheel and the tyre to a given peripheral velocity at the instant of landing. Just before

landing, when the aircraft was moving at a horizontal velocity of, say, 50 m.p.h., the wheel was at rest relative to the aircraft. When the tyre first touched the ground it must skid; it would then start to accelerate, but relative skidding between the tyre and the ground would continue for a considerable time—until the wheel had been able to reach the full peripheral velocity. From the instant at which the tyre touched the ground to the instant at which the reaction on the tyre was a maximum—which was usually, but not always, the instant when the aircraft had come to rest vertically—was generally of the order of 1/10th of a second. Therefore, the tyre had to be accelerated from zero angular velocity to very considerable angular velocity in about 1/10th of a second. Due to this frictional force there was a big tangential force acting on the tyre, and also on the undercarriage, which was of interest in connection with the design of the undercarriage. It would increase the value of the comparative figures given in the paper if there could be added the relative polar moments of inertia of the three comparable wheels.

Another item on which he would like information—and he had been looking for it for many years—was the angle of deviation from the straight track of a pneumatic-tyred wheel if it were moving forward under the influence of a load at right angles to the plane containing the wheel. If one had a truck with four pneumatic-tyred wheels and pushed it forward slowly, at the same time pulling it laterally (in the direction of the axles), it would travel at an angle from the straight line of push. This angle was of considerable interest in aircraft in connection with the calculation of the loads on axles during landing, but he had never yet been able to obtain quantitative information, and it was not easy to obtain experimentally.

Mr. FELLOWES: Replying to the question as to the impact test and the measurement of the resistance of a tyre, he illustrated the drop test used by the Dunlop Company. They used a channel iron frame, across which (near the bottom) there was an axle, with a wheel and tyre fitted to the centre of it. In the channels on the two uprights there were runners, working a pulley situated in the centre of the cross-bar at the top of the frame, and immediately above the tyre. From the pulley a weight was dropped on to the tyre. The units of impact were based on the weight and distance of the drop, and also on the shape of the tool, its length, and the extent of its penetration into the tyre. The units of force mentioned in the paper were illustrative of that method of testing, and meant nothing to the uninitiated.

As to the suggestion that, when using extra low pressure tyres on aircraft, the oleo rubber or other means of suspension could be eliminated, he said that his experience and the evidence that had been placed before him was such that that was out of the question, even though it might have been suggested in other countries that one could land on a deflated tyre. The problem as to whether or not a machine could land on a deflated tyre of the extra low pressure type was a very big one. He demonstrated that he could almost collapse the deflated extra low pressure tyre by pushing it with the hands, and he was inclined to think that a pilot who could land a machine safely on such a tyre was a very fine pilot.

Mr. PITTMAN: Dealing with the question of how the low pressure tyre behaved on meeting an obstacle when crossing the aerodrome, and the point that the angle of approach varied when using a low pressure tyre, he asked whether the low pressure tyre would " give " more to the obstacle due to its greater flexibility, and automatically alter the angle of approach more in line with the high pressure tyre.

Dealing with the tubes having puncture-proof sealings inside them, he asked how much extra weight had to be carried in the undercarriage when those tubes were used, and how much air capacity the sealings displaced.

Mr. FELLOWES: In a way one could say that the low pressure of the extra low pressure tyre did more than counterbalance the angle of approach over an obstacle, because the tyre, by reason of the low pressure, tended to envelop the

obstacle. But where there was an undulation the question of angle of approach in relation to diameter was, if anything, worse with a low pressure than with a high pressure tyre. He believed that that was borne out by experience with cross-country vehicles. In the past it had been found always that the larger the wheel the more easily one could negotiate obstacles on unmade roads or across country. The artillery wheel on guns could not possibly have a diameter of less than about 5ft. 6ins.; a big angle of approach was wanted to climb over the obstacle, rather than a small low pressure tyre to push against it, and he believed the push was more serious with the low pressure tyre than with the high pressure tyre.

Dealing with the weight increase due to the use of a cellular liner or other puncture-sealing medium, he said that one could not add any rubber material, of course, without increasing weight, but experience had shown that the extra weight was more than counterbalanced by the advantage of the puncture-saving devices, particularly overseas. As a rough estimate, the cellular liner might weigh as much as 9lbs. for a 6in. tyre. The advantage of the plastic tube over the cellular liner was in weight. In the one case one was trying to increase the distance between the air and ground, and in the other case one was trying to close the puncture. The extra weight involved in the use of the plastic tube was only about half that involved in the use of the liner. The air capacity replaced by the liner was practically nil. In Fig. 4 he had indicated the amount of pressure increase due to deflection under static load. It was practically nothing. If a tyre were made smaller to the extent of the volume of the liner or plastic tube, that fact would have very little bearing on the performance of the tyre.

The CHAIRMAN: He supposed Mr. Fellowes would not propose the use of the special tyre in the tropics?

Mr. FELLOWES: No.

Mr. TARRIS: He asked if the 65 D.B. failing load referred to was the test load applied vertically or with the axle at 15° to the ground, and what was the basis of the safety factors of 4 and 5 for aeroplane tyres? Did he express that as a bursting failure at recommended pressures? He also asked for the author's view on the use of plain bearings versus roller bearings.

Mr. FELLOWES: The 65 D.B. was taken on the vertical load and not at the 15° angle. The safety factor of from 4 to 5 on a cover was based on the inflation pressure required to burst a tyre. The question of bearings was rather outside the scope of the wheel manufacturer. The type of bearings to be used was usually specified by the aircraft designer, and naturally must depend on the type of axle.

Dr. DOUGLAS (Royal Aircraft Establishment): Referring to the author's comparison of three different types of wheel, each of which was stated to be suitable to carry 3,000lbs., he asked on what basis the comparative load carrying capacities were arrived at? Discussing the relative merits of spats and fairings as a means of reducing undercarriage drag, he said that one could get equally good results by enclosing the complete wheel and joint in a spat or by suitably fairing the individual parts, but one must be very careful indeed with regard to the fairing design to avoid interference, and leaks must be avoided.

Mr. FELLOWES: Replying to the question as to the datum for the three types of tyres to carry the 3,000lbs. load, he said that the load-carrying capacity of a tyre was laid down by the Air Ministry, and a high pressure tyre had a 33 per cent. deflection, carrying a certain load. For a low pressure tyre to carry the same load, one could arrive at the sectional size of the tyre. The original basis was on the high pressure tyre as laid down by the Air Ministry, and that basis was on the deflection for load support. Fairing was more a matter for the aircraft designer than the wheel manufacturer, although, naturally, where the wheel and tyre manufacturer could provide a fairing which was incorporated as a strut or axle stud joint, so much the better.

Flight Lieut. W. E. P. JOHNSON: Having flown machines fitted with all types of tyres, he preferred the one which he called the "doughnut." He had been surprised by the remarks made concerning the difficulty of surmounting obstacles on aerodromes. The full "doughnut" tyre was so good for getting over obstacles that one had to be careful to ensure that the chocks used were large enough. He also asked what tests were carried out to ascertain the side loads which tyres would stand. Again, he asked if the advertised pressures were as critical as the tyre manufacturers would have us believe, and, if so, why the manufacturers did not indicate by mould marks on the tyres the pressures to which they should be inflated. His final question concerned the extent to which a rise of temperature such as would be experienced when flying in a hot climate would affect the safety factor of a tyre if pressures are indeed so critical. It appeared that it should be easy to work that out, but probably there was more in it mechanically than met the eye.

Mr. FELLOWES: Commenting on the point that large chocks must be used for aircraft fitted with low pressure tyres, said he would be inclined to attribute that to the lower intensity of pressure and the greater area of the chock covered tending to make the wheel climb. But that was not quite comparable with overcoming an obstacle such as, for instance, a sandbank, where the wheels would tend to dig themselves in. Perhaps his remarks on this subject had been more applicable to soft surfaces than to hard, resistant obstacles. When running against a soft sandbank the diameter of the tyre was a great factor. Perhaps the tyres used by Flight Lieut. Johnson were over-size, having large diameter. The low pressure tyres were usually smaller in diameter.

The question of the method of testing wheels was a subject for a paper in itself.

As to the marking of the advertised pressures on the sides of tyres, he agreed that the low pressure tyres were becoming large enough to enable the manufacturers to write a story on them, but in the case of tyres used for loads varying from, say, 1,500 to 3,000lbs. in varying stages, it was necessary to mark each pressure and each load. Commercial vehicle tyres, in the past, were marked with the maximum load and the minimum inflation pressure, but that had not made any difference; the drivers of the vehicles still ran the tyres as they thought they would.

Temperature rise could be worked out easily, but if a machine were flying from this country to a tropical country such as India, the pressure rise due to temperature in a tyre inflated at 35lbs. per sq. inch pressure probably would not be more than 1 or 2lbs. He had had experience with commercial vehicles in tropical countries last year, and he suggested that in that case the pressure rise was due less to atmospheric temperature than to the contact of the tyres with the hot ground surfaces.

Mr. W. E. GRAY: He asked for an explanation of some apparent disparities in the author's figures. In one of the tables the author had given an inflation pressure for the low pressure tyre of 20lbs. per sq. inch, and that had risen to 21.5lbs. when the static load was applied. Yet the loading given when he had divided the weight by the area covered had worked out at 26lbs., when the aeroplane was on the ground. That was considerably different from the inflation pressure. In the case of the high pressure tyres the figures were much closer—51 and 53—and as the pressure was reduced the difference was very much wider.

Mr. FELLOWES: In dealing with the contact pressure in relation to inflation pressure there were several factors to be taken into consideration. It sounded reasonable to assume that the contact pressure on the ground should be the same as the inflation pressure. In the case of a thin rubber balloon that might be so, but in the case of a pneumatic tyre cover, made up of fabric plies, which imparted certain mechanical strength, there was a difference in the contact pressure due to the deformation and stiffness of the tyre cover. The figures quoted in the paper were actual results.

REVIEWS

Jane's All the World's Aircraft, 1932

Sampson Low, Marston and Co. Two guineas.

The 1932 edition of this well-known work of reference follows its predecessors in the general arrangement of the contents, and well maintains the previous high standard of excellence.

It is of interest to note the considerable progress made in the production of new designs during the past year, as shown by the new illustrations necessary. The British section contains 11 more new illustrations than were necessary last year, the French section 20, the German section 24 and the Italian 20, while there is a decrease in the American section of 10, and small decreases in the Dutch and Czechoslovakian sections. This result is certainly indicative of the enterprise to be expected of a new industry in facing the world depression. It may also be noted in this connection that it has been necessary to provide 25 new pages of information and illustrations as compared with the previous edition in spite of the ingenuity of the editors in condensing the necessary data.

Another interesting feature which strikes one in turning over the pages is the increase in the number of monoplane types, though this increase is less marked in the British section than elsewhere, possibly owing to the influence of Service practice on civil aviation in England being greater than in other countries. Both in England and America the biplane type seems to be holding its own for military types, doubtless due to the greater wing rigidity which is inherent in the biplane wing.

The pure cantilever monoplane seems to have obtained most favour in Germany, though all countries can show examples, while strut-braced monoplanes, either high or low wing, are common in most countries. So far, one has not noticed an example of the middle wing monoplane. Possibly questions of view and interference of wing structure with the internal arrangement of the fuselage may provide practical objections to its adoption.

It is also interesting to note the resurrection of the wire-braced monoplane in certain American types designed for high speed. This development, doubtless influenced by Schneider Cup practice, has spread into Service types, as illustrated by a two-seater fighter designed by the Curtiss Company of America.

Signs are not wanting that the monoplane may before long break into the biplane stronghold of the British Air Ministry; the interesting new bomber designed by the Fairey Aviation Company is possibly indicative of such a development.

Machines of unusual type, such as the Westland Pterodactyl, do not seem to be increasing in number notably, though the autogiro seems to be built in more countries than formerly.

There is unquestionably more attention being paid in all countries to the reduction of parasite resistance, though the adoption of retractable undercarriages does not seem to be making much progress, possibly owing to mechanical difficulties.

There is not much to comment on in the engine section, but the popularity of the four-cylinder in-line type for light aeroplanes seems to continue in spite of the challenge of the radial, and there is no increase in the number of Diesel types, though those firms which have previously produced this type still continue to do so.

Among the larger petrol engines it is interesting to note the French tendency in the direction of broad arrow engines with 12 or 18 cylinders and also the numerous carburettors fitted to the French engines. The comparative scarcity of water-cooled types is noticeable in the American section, where the air-cooled radial seems to be more than holding its own.

Histoire de l'Aeronautique

de Charles Dollfus and Henri Bouche. L'Illustration. 250 francs.

This volume belongs to that class of book in which the illustrations are more important than the reading matter, and it has seldom been our lot to peruse a book which is more thoroughly illustrated and in which the quality of the illustrations is so high.

The legendary stage of aeronautics is copiously dealt with and very many of the illustrations have not, as far as I know, been published before, examples having been found even in Egyptian and Chinese prints and carvings. Many coloured reproductions are given of the early balloons and certain portraits of early aeronauts; these are magnificently reproduced. Among others it is interesting to note the design for a dirigible hangar projected by General Meusnier in 1785; it is curiously similar to those in use to-day.

It is pleasant to note that full appreciation is given to the early work of Sir George Cayley, who is rightly described as " le veritable inventeur de l'aeroplane "; illustrations are given of his helicopter-aeroplane of 1843, accompanied by an excellent portrait of Sir George Cayley himself. Among the French experimenters of the early 19th century the name of Lambertye is new to me. This gentleman not only produced a machine of the ornithopter type for military observation, but went so far as to design the uniforms for the future flying corps.

Coming to more recent times, a full description with illustrations is given of Henson's and Stringfellow's work. As the first who succeeded in making a flight with an aeroplane, Henson's place as a pioneer of aviation is unassailable, and it is interesting to note how excellent his detailed design was. Full justice is given to him here and drawings are reproduced of his steam engine, hollow spar construction, rib design, etc.

The details given of the construction and power plant of the French dirigible, La France, constructed in 1884, are of considerable interest. This machine was the first to make a controlled flight with a crew and was driven by an electric motor supplied with current by a primary battery.

Ader's work is very fully dealt with, and one notes that the steam engine he used weighed between 6 and 7lbs. per horse-power and that the weight per horse-power of the complete machine was 33lbs. Whether he actually made what could be called a flight during the trials may be doubtful, but the machine was clearly hopelessly unstable and sustained flight was consequently impossible. If Ader had studied and appreciated the earlier work of Henson and Stringfellow, France might have acquired the honour which has since passed to the United States, through the work of the Wright brothers, of producing the first successful man-carrying aeroplane. Ader's mechanical ingenuity is indisputable and of the highest order.

It is unfortunate in a work of this kind that no reference is made to the work of the Englishman, Phillips, who was an early experimenter with the multiplane form of construction. He is principally remembered, however, for his work on aerofoil sections, and the term " Phillips' entry " for describing a particular shape of the front portion of an aerofoil is still in use in this country.

Otto Lilienthal's work does not perhaps receive the recognition that is his due. He was really the first to make scientific experiments in man flight, using gravity as a motor, and it can be said that the interest which was stimulated by

his success led directly to the success of the Wright brothers. American interest was aroused largely by Octave Chanute, who had a keen appreciation of Lilienthal's methods.

To Santos Dumont is due the honour of stimulating French interest in aeronautics. His early pioneer dirigible flights, followed by his first aeroplane flight in Europe on the 12th November, 1906, were remarkable efforts. He had, however, an important advantage over the earlier experimenters in that the development of the petrol engine had provided him with a light motor, in fact the automobile engine with which he accomplished his first aeroplane flight was the first of the modern aero engines; the line of succession from this engine leads directly to the Rolls-Royce Schneider Cup engine of 1931.

The Wright brothers' work in America is dealt with adequately. This work, in the skill with which it was planned and the ability with which it was carried out is beyond all praise and deservedly led to the crowning achievement of the 17th December, 1903, when they made the first man-carrying flight on a power-driven aeroplane. Although the particular type of aeroplane which they used is now obsolete, they were the first to realise that an aeroplane must have three controls—rudder, elevator and ailerons (or warping wings).

Coming to more recent days, the work of all the better known pioneers such as Blériot, Farman, Cody, Curtiss, is illustrated and described, though the early work in England of Sir A. V. Roe is unaccountably dismissed in a few lines. His efforts, carried to a successful issue under incredible difficulties, are worthy of more recognition than is given to them here.

Details are given of all the notable pre-war flights. Blériot's cross-Channel flight, Chavez crossing of the Alps, etc., with many photographs, after which many pages are devoted to aviation during the war. These pages are notable for their numerous illustrations, which form an excellent record of war-time aircraft. One notes with interest that a machine in use by ourselves in the Dardanelles is described as a primitive English biplane, whereas it is really a French Voisin.

The final section of the book brings the story to the present day, and is a mine of information on the development of commercial aviation, the light aeroplane for private use, aerodromes, etc., and deals also with the post-war development in military aircraft. This is generally well dealt with, though less than justice has been done to the English share in the development of the light aeroplane.

The book is an invaluable work of reference and is worthy of the reputation of the authors.

The Beauty of Flight

Dr. Manfred Curry. John Miles, Ltd. 15/- net.

This book consists of a short introduction dealing with the usual cloud forms and a large number of photographs of clouds, aeroplanes, etc. The preface is by the President of the Society, Mr. C. R. Fairey, who has in this way marked the book as one worthy of special attention.

It is, beyond question, the most magnificent collection of air photographs which has ever been brought together. The soft rolling masses of the cumulus cloud, the menacing darkness of the thunder cloud, the feathery delicacy of the cirrus cloud are here shown in all their beauty of shape and tone, the beauty of Nature herself untouched by the hand of man.

Many of these photographs being taken at height, it is to the aeroplane that we owe this new revelation of Nature. It is given to those to go up in aeroplanes to see the wonders of the air.

Dr. Manfred Curry has done a great service to everyone in producing this collection, and the taste he has shown in selection, arrangement and printing

are worthy of the subject. It is a book which no lover of beauty should be without.

Britain's Air Peril

By Major C. C. Turner, A.F.R.Ae.S. Sir Isaac Pitman and Sons, Ltd. 5/-.

Major Turner is well known to all interested in aeronautics as having contributed much of value to aeronautical literature, and he has written this, his latest book, with the object of bringing home to the man in the street the effect of the recent disarmament proposals on the use and development of British aircraft.

He deals extensively with the use of aircraft in war, brings out from statistical information the position of the British Air Force as compared with other nations from the point of view of strength, discusses the effect of aerial bombing on towns, and is an advocate for the strengthening of the Air Force, claiming that by doing so the total cost of the defence of this country could be reduced.

There is no doubt that the larger the Air Force, enabling a greater number of interceptor and fighter squadrons to be provided for home defence, the greater the security of this country from aerial attack; but this matter, considering the additional cost that would be involved, cannot be considered apart from the question of finance. At present this country is taxed to the hilt, in fact to the extent that a further increase of taxation would almost certainly reduce the yield and the necessary money can only therefore be found by reduction of other expenditure. As it is unlikely that consent could be obtained to the reduction of social expenditure, it would be necessary to obtain the sum required by reducing the amount allocated to the Navy or Army, or both.

The total amount expended on defence by this country in the 1932-1933 estimates is £86,937,000, made up as follows:—

Navy	£41,611,000
Army	28,182,000
Air Force	17,144,000
	£86,937,000

and on the assumption that the total cannot be increased it is necessary to inquire as to the possibility of reducing the expenditure on the Army and Navy.

There is no doubt that both these Services could make out nearly as good a case as the Air Force for increase of expenditure. In the case of the Navy, there is certainly a serious shortage of cruisers which might jeopardise the food supplies of the country during war, while the Army has been reduced to the extent that it is hardly equal to its task of keeping order on the more remote frontiers of our Empire.

But is the position of this country so insecure from an attack as has been supposed? Major Turner, quite rightly, treats with complete unbelief the stories current in the popular Press, of the teaspoonfuls of powder which can exterminate the population of a large city, or the poison gas of incredible potency. But there is no doubt that an air attack on London carried out on a large scale with modern aircraft and modern bombs would temporarily paralyse the city and might lead to the complete demoralisation of the population. But it is doubtful if we are so helpless as is often supposed, as is illustrated by the results of the R.A.F. air exercises in 1931, when four-fifths of the raiding aircraft were destroyed in three days. In the case of these exercises the effect of ground anti-aircraft fire could obviously not be tested, and the development of anti-aircraft armament has kept pace with the development of the aircraft themselves.

It would seem, therefore, that in providing an Air Force of the highest possible quality, unsurpassed by any country in the quality of men and machines, the Air Ministry have done the best that is possible in providing for the security of the country within the financial limit to which they are confined and that any improvement in this security can only be obtained by increasing the Air Force vote, which is certainly impracticable at the present moment.

Whether the present allocation of money expended by this country in defence between the three Services is the best possible is a matter on which much could be said, but it certainly cannot be discussed without considering the claims of all of the three Services.

Major Turner's book should have the effect of leading the ordinary man to understand better the problems which the Royal Air Force have to meet, and should increase popular knowledge in the newest and least understood member of the Fighting Services.

PROCEEDINGS

Seventh Meeting, First Half, 68th Session

The Seventh Meeting of the First Half of the 68th Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, December 8th, 1932, when a paper by Lieut. J. S. A. Salt, R.E., on "Air Survey," was read and discussed. Mr. H. E. Wimperis (Director of Scientific Research at the Air Ministry) presided.

The Chairman: For the last three years Lieut. Salt had been research member of the Air Survey Committee of the War Office. Though this was a War Office Committee, other interests were represented on it, as, for instance, the Air Ministry and the Royal Navy, and it was charged with all the new work which had to be thought out and accomplished—so far as the British Government was concerned—with regard to survey from the air. Lieut. Salt was trained at the Survey School at Chatham, and had had actual experience of survey work, both on the ground and in the air; he had carried out surveys from the air in Egypt, in Sinai and in the Aden Protectorate, so that he was acquainted with both the theory and the practice of the subject.

AIR SURVEY

BY

LIEUT. J. S. A. SALT, R.E.

1. *The Social Function of Survey*

In a country like England, where, owing to the vision of our forefathers, accurate maps are available for almost any purpose, we are apt to take their existence for granted and to forget the foresight, time and labour necessary for their preparation and constant revision. For purposes of engineering and administration there are the sheets at scales of 6 ins. and 25 ins. to one mile, together with some intermediate and even larger scales; the soldier, and in particular the gunner, prefers a map on a scale of 1/25,000, or about $2\frac{1}{2}$ ins. to one mile; for the tourist, especially walkers and cyclists, the 1 in. to the mile series provides accurate information, fascinating to read, and beautiful to look at; the motorist uses a $\frac{1}{4}$ in. map, of which series a special edition with many original features is produced for the airman; and finally the map of England at 10 ins. to the mile is available for those who have the fortune to do their long-distance journeys by air. All these benefits, to be had for the price of a few shillings at any stationer's shop, are the ultimate result of the wisdom of those who initiated the Ordnance Survey of Great Britain. It is a remarkable fact that in nearly every country the initiative in survey matters has been taken by the army, and that civilian administrators have seldom recognised the necessity of maps until the lack of them has forced attention to the problem. Many cases could be given of misguided attempts to economise on survey, with the result that development schemes have been undertaken with insufficient reconnaissance and consequent waste of resources. In one case, for instance, of a railway constructed on the Gold Coast, subsequent readjustment of the line cost £1,500,000. All this

might have been saved by previous mapping of the whole area, the cost of which would have been one or two per cent. of the above sum. As it is, both the money and the map have been lost. In view of the drastic economies now demanded of all survey organisations, it would appear that it is more fashionable to ignore the lessons of the past and to shirk provision for the future.

The increasing importance of air communications in the British Empire leads to a consideration of the type of map best suited to purposes of navigation and identification of places. A map on a scale of 1/1,000,000 (or about 16 miles to the inch) would satisfy the demands of the navigator, while for identification purposes a scale of 1/250,000 (or $\frac{1}{4}$ in. to the mile) is a suitable compromise with other normal requirements. A series of sheets on these two scales would adequately and reasonably fulfil all demands that are likely to be made, and should be the aim and object of any scheme of mapping for flying purposes.

Now by far the greater part of the Empire is virtually unsurveyed, and, as a result of present policy, the existing maps are rapidly becoming out of date. As the real, but unrecognised, need for survey increases each year, a parallel need evolves for some technique which will speed up the ordinary ground survey operations, so that not only may the lost ground be recovered but a great deal of new survey carried out. It is this particular function that air survey is admirably suited to fulfil. The methods exist whereby our vital survey needs can be met and on which an efficient organisation can be evolved. We shall examine below the broad basis of such a technique and discuss finally the necessary line of approach to enable it to be carried out.

2. *Photography as an Aid to Survey*

Suppose that from some station commanding a good field of view a photograph is taken with the axis of the camera horizontal. Then from a knowledge of the calibration data of the camera we may construct on the photograph a graticule system depicting angles subtended at the perspective centre, in the same way that parallels of latitude and meridians of longitude on the surface of the earth depict angles subtended at its centre. In this case azimuths will be represented by vertical straight lines, and elevations by hyperbolic curves convex to the horizontal. With a knowledge, therefore, of the orientation of the camera axis at exposure, we have a pictorial record of angles in space to all objects in the field of view, such as might have been obtained by an observer with a theodolite. Suppose, now, that the exact position of the camera station is known and that another photograph is taken from a second known station covering much the same field of view from a different aspect. From the data provided by the two photographs the positions in space of all points in the common field of view can be determined by means of two-ray intersections. Various methods of applying this principle have been evolved, ranging from actual determination of angles, followed by computation, to completely automatic plotting.

The photography of an area from two different points of view opens up the possibility of stereoscopy. In ordinary life, by having two eyes separated by a short eye-base (about $2\frac{1}{2}$ ins.) we obtain two slightly different plane views of the same object space, from which our brains interpret a picture in the solid. This faculty is seldom consciously called into play, since there are usually other factors enabling us to estimate relative distances, but it is interesting to note that in the animal world it is possessed only by beasts of prey, the eyes of herbivorous animals being so situated that they view the world as a flat panorama. Where the base separating the two viewpoints is large, then by observing the two photographs in a stereoscope we may obtain the same view of the landscape as would be obtained by a giant possessing the large eye-base. The country is seen in relief as a small-scale plastic model. This property is made use of in automatic plotting machines.

The application of this method is restricted by the limitation of the field of view. Though of great value in hilly country, it is of little value in flat or gently undulating regions. The advent of flying offered freedom from this restriction, by virtue of the almost unlimited field of view available. Since then, the application of air photography to every variety of survey has been closely studied, and methods are now available to suit every kind of need.

3. *General Theory of Stereoscopic Pairs*

When two overlapping photographs are taken from known ground stations and at measured orientations, it is a simple matter to place them in a plotting machine so that they are in the same angular relationship one with the other as they were at exposure. By using an ocular system equivalent to placing the eyes in the two positions originally occupied by the lens, so that the left eye observes the left-hand photograph and *vice versa*, all angular relationships between the camera stations and the object space are preserved. The plastic model is, therefore, true in shape, but at a different scale. In the case of air photographs, however, the exact positions of the air stations are not known, neither are the orientations of the photographs. Some other procedure must, therefore, be devised.

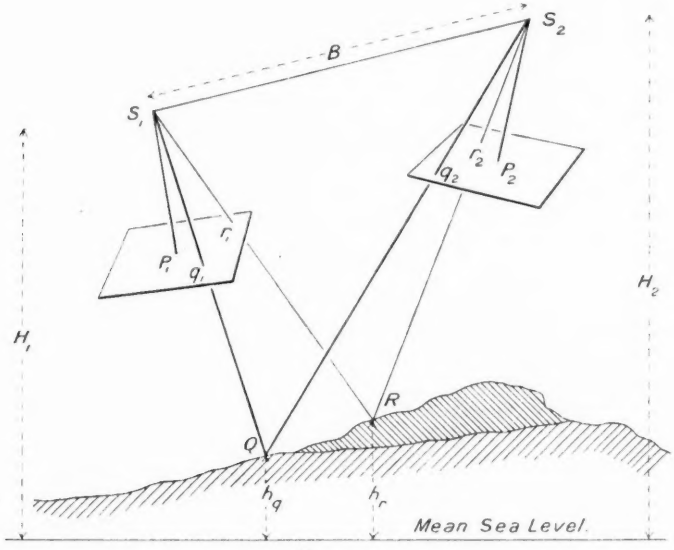


FIG. 1.

Fig. 1 shows two photographs taken from air stations S_1 and S_2, and covering, in part, a common area of ground. In order to simplify the diagram, and the ideas to be inferred from it, we shall deal with the equivalent positives rather than the negatives. S_1 and S_2 are, therefore, the two perspective centres; from which perpendiculars to the plane of each plate meet the plate in the principal points P_1 and P_2. The angular relationship in space between S_1 P_1 and S_2 P_2, defined in any organised manner, will express the angular relationship between the two photographs. Now the images of a ground point Q will lie at q_1 and q_2, in the plane of the triangle Q S_1 S_2, which contains the air base S_1 S_2 and is known as a basal plane. Similarly the images r_1 and r_2 lie in the same basal

plane as the ground point *R*. If an instrument is devised, therefore, in which it is possible to orient the photographs in such a way that they occupy the same angular relationships as they did at exposure, a condition of such true orientation will be that pairs of corresponding images must lie in the same basal planes. Now it can be proved that if the photographs can be adjusted so that any five pairs of corresponding points lie in the same basal planes, then all other pairs will lie similarly in their basal planes, and the photographs are correctly oriented (Fourcade. Transactions of Royal Society of South Africa. Vol. XIV. Part I. (1926)). To achieve this we must devise an instrument which, as far as the *pair* of photographs are concerned, affords five degrees of freedom. By a suitably organised manner of observing on five pairs of points, departures from the co-planar condition may be adjusted, and true orientation achieved. The result will be a plastic picture in three dimensions. We do not yet, however, know either the orientation or the scale of this relief model in space, since it is, so far, only related to an air base whose orientation and length are themselves unknown.

To relate this stereoscopic image to the ground we require three ground points of which the true positions and heights have been determined. The positions of these three images in the relief model are adjusted to fit the ground data by altering the scale and orientation of the relief model *as a whole*. The previous correspondence adjustments are kept fixed. The whole process is merely a generalised case of three-point suspension. A fourth control point supplies one condition of redundancy, and therefore a check.

4. *Plotting Machines*

A plotting machine is an instrument for reconstructing from a pair of overlapping photographs a spacial model on which the detail and contours may be traced out and plotted on a drawing board automatically. In order to define the point in space observed, a floating mark is used; that is to say, a conventional mark whose apparent position in space may be altered by means of certain mechanisms connected with the drawing pencil. By adjusting the mark to lie coincident with the ground at any point, the position and height of that point are automatically recorded.

There are many types of plotting machine, differing widely in their optics and mechanisms, but the general principles of their operation remain the same and entail three stages:—

(1) Internal orientation.
(2) External orientation.
(3) Setting of scale and orientation of relief model.

(1) Every plotting machine consists essentially of two goniometers, which are dimensional replicas of the camera with which the photographs were taken, and are fitted with similar lenses. Internal orientation consists of the setting of the pair of photographs in their goniometers so that they occupy the same relationship to the rear nodal point of the lens as they did at exposure, and will depend upon the calibration of the particular camera used. Angular relationships between points on the plates and their perspective centres are now true.

(2) External orientation, or the relative orientation of the pair of goniometers one with the other, consists of the adjustment into their respective basal planes of five pairs of corresponding points. Want of correspondence can be observed by means of the floating mark, and eliminated by means of setting movements. Internal orientation is not changed, and the reconstruction of the stereoscopic model is now complete as regards shape, though unknown in scale and orientation as a whole.

(3) The scale and orientation of the relief model may be obtained by making the plotted positions and heights of three points agree with the data obtained

from ground survey. Checks may be made on any number of other points available. Detail is then drawn by operating the mechanism so that the floating mark follows the features of the country. By clamping one movement the floating mark may be forced to move in a definite horizontal plane; its path when in apparent contact with the ground will then trace out a contour.

The efficacy of a plotting machine will depend upon its ability to carry out the above three operations in a direct manner and in the shortest possible time. Most instruments, for instance, cannot carry out operation (3) without upsetting the previous adjustments of operation (2), arriving at the correct result either by means of computation or by successive approximation. The only instrument built on fundamentally correct design is the Fourcade Stereogoniometer (Barr and Stroud). The results obtained from modern plotting machines are of a very high order of accuracy, and, within their own limitations, provide a very elegant solution.

The chief disadvantages of plotting machines are their high cost (£3,000-£4,000), the—at present—somewhat exacting demands made upon the kind and extent of ground control, and the fact that only one pair of plates can be plotted at once. These factors lead at once to an investigation of other methods of plotting possessing greater freedom in these respects.

5. *Simplifications in Case of Vertical Photography*

Consider the case of a pair of overlapping photographs taken as far as possible at the same height and with the axis of the camera vertical. In practice, a close approximation to this can be achieved. When set in a plotting machine, therefore, the two photographs will lie in very nearly the same plane. Consider, therefore, a simplified form of stereoscope in which the photograph holders are not goniometers but flat turntables. The photographs are placed on the turntables, with their principal points at the centres of rotation, and are oriented in their own plane. When viewed stereoscopically they will present a relief model, though slightly distorted, since angular relationships are no longer true. Provided, however, that the tilts on the photographs are small, and that we possess a series of spot heights obtained by a ground survey covering the common overlap, we may draw contours on this relief model which are sufficiently accurate for topographic purposes. The instrument necessary is small, of simple construction, and correspondingly cheap. The floating mark consists in this case of a grid which can be adjusted so as to appear to float horizontally in space at any desired height. The contours are drawn on the photographs themselves and are then similar in nature to detail. We require now some method of plotting detail.

A vertical photograph of flat country would (within the limitations of lens distortion) be a true plan of the ground. If a photograph is tilted the result is no longer a true plan, since the scale will be different in different parts of the picture; being, in fact, smaller on that side of the negative tilted towards the ground and *vice versa*. Now it can be shown that the distortion in position of any point in this way takes place radially from a point known as the isocentre, situated at a distance $f \tan \theta/2$ from the principal point and in the direction of tilt, where f=focal length of lens, and θ=angle of tilt. Angles subtended at the isocentre by points on the photograph and measured with a protractor will be the same as angles subtended by the corresponding points on the ground at the ground point corresponding to the isocentre, such as could be measured with a theodolite. In practice, however, the ground is seldom absolutely flat, and there are further distortions due to variations in ground height. On a vertical photograph, for instance, every contour is photographed at a different scale, the tops of hills being at a larger scale than the bottoms of valleys. These height distortions take place radially from the plumb point, which is the point where a

vertical line through the rear nodal point of the lens cuts the plane of the photograph. It will lie at a distance of $f \tan \theta$ from the principal point, and in the direction of tilt. On a truly vertical photograph, therefore, the plumb point coincides with the principal point, which is then, even in the case of hilly country, angle true. In the case of a tilted photograph of hilly country there is clearly no point from which angles are true, since tilt distortions are radial from the isocentre and height distortions from the plumb point. Furthermore, there is no means of directly obtaining the tilt, since a body, such as an aircraft, moving in a homogeneous medium has no means of differentiating between acceleration and gravity. It is found, however, that provided tilts can be kept to within two degrees of the vertical, and ground heights do not vary by more than 10 per cent. of the altitude of the aircraft, we may take the principal point itself as being angle true. This, being a function of the camera only, is available from the calibration data.

Suppose, now, that a strip of nearly vertical photographs are taken at approximately the same height and in such a way that each photograph overlaps the next by about 60 per cent. There will thus be a small area, in width 20 per cent. of the width of a photograph, common to every three successive photographs. In view of the radial assumption discussed above, each photograph may be considered as the data obtained by an observer on the ground, situated at the point of detail corresponding to the principal point, and taking rounds of angles to all points of detail appearing on the photograph. We now have sufficient data to build up a graphical triangulation, dependent on angular relationships only, which will determine the true relative positions of photographs along the strip. This is carried out on celluloid and is known as a minor control plot. It will be true to shape, and at some definite but unknown scale. Any point of detail may now be fixed by a two-ray—or in some cases a three-ray—intersection from the principal points of the photographs on which its image lies. If the positions of any two such points have been determined by ground survey, then the scale and orientation of the minor control plot are fixed.

When it is required to survey a large area, strips are flown parallel to each other and with a lateral overlap of about 25 per cent. between adjacent strips. In this case a minor control plot is constructed for each strip, and these will all be at different scales. The next stage, therefore, is to bring them all to some common scale. A grid, known as a master grid, is constructed to represent 1,000-metre squares (say) on some definite scale approximating to the scale of the photographs. On this are plotted all the points whose positions are available from ground survey and which can be identified on the photographs and intersected on the minor control plots. A control equivalent to a second order triangulation will be sufficient. All strips are then tied in to this framework of ground control, suitable points being chosen in the common lateral overlaps to ensure exact agreement between adjacent strips. The result is a series of principal point traverses plotted to the same scale and in their correct relative positions on the master grid.

Finally a sheet of celluloid of convenient size is placed over the master grid and the principal point traverses are traced off. On this sheet the detail is plotted from the photographs by placing them under the corresponding principal points and in the correct orientation, and carrying out a series of intersections and interpolations. All detail drawn in this way will be plottably accurate. Contours are transferred from the photographs similarly.

All mapping material thus obtained must be fair drawn according to the conventional signs and symbols adopted for the map. Plates are then prepared for as many colours as are required, and the map is reproduced and printed in the ordinary way.

The advantages of this method are:—

(1) Simpler and cheaper equipment may be used.
(2) Film negatives and paper prints are normal, with correspondingly simpler air photographic problems.
(3) Less ground control is required, and no hard and fast layout is necessary. Whatever control there is may be used to the best advantage.
(4) The work of plotting may be subdivided among a large number of draughtsmen, thereby increasing the speed of map production.

6. *The Air Photographic Problem*

With a view to carrying out the above technique we may state the demands of the surveyor as follows:—

(1) Photographs should be taken in strips, flying a straight course at a constant height, usually 15,000 ft. above ground level.
(2) The fore and aft overlap between photographs along a strip should be 60 per cent.
(3) The lateral overlap between adjacent strips should be 25 per cent.
(4) The tilt of the camera at exposure should be kept as small as possible, and should not exceed 2°.

These are exacting demands, but with the exception of (2), which is merely a question of time interval between exposures, the same considerations would arise if the problem were merely to cover an area photographically in the most economical manner.

The characteristics desirable in an aircraft for survey photographic work may be summarised as follows:—

(1) Endurance.—An endurance of 6-8 hours is desirable.
(2) Comfort.—To ensure accuracy in navigation and camera operation under extreme cold, comfort is essential.
(3) Stability.—The greater the aerodynamic stability, the better the quality of flying.
(4) View.—The pilot must have a good view ahead and to both sides, and the instruments used for maintaining the correct course, height, and level, should all be grouped near to his normal line of sight.
(5) Speed and Climbing.—Speed is useful in climbing to the required height and when photographing some way from the aerodrome. For actual photography, however, a steady cruising speed of about 100 m.p.h. is probably the most suitable. When photographing hilly country, a machine with high performance is required to reach the necessary height with full photographic load.
(6) Multi-engine.—For large surveys, and particularly in country unfriendly to a forced landing, a triple-engined machine, capable of maintaining level flight on any two engines, has the advantage of greater security.

To photograph a strip it is usually necessary either to fly between two observed points, maintaining a straight and level course, or to fly over a given point maintaining thereafter a given compass course. Both of these methods entail the determination, either directly or indirectly, of the speed and direction of the wind. This, added vectorially to the air speed, determines the ground speed, the difference in direction between the two latter being the angle of drift. The duties of the photographer are:—

(1) To determine the wind speed and direction, and direct the pilot on to the correct course.
(2) To turn the camera through the angle of drift so that the photographs are not "crabbed."

(3) To trim the camera level when steady flight at the required height has been achieved.

(4) To set the time interval between exposures necessary to produce the required fore and aft overlap.

The time taken in carrying out the above operations will depend on the methods and instruments used, and on the skill of the photographer and pilot, but the interval between taking off and starting photography, even close to the aerodrome, will seldom be less than 50 minutes. Sound meteorological information is therefore essential, particularly in cases where changes of weather are rapid.

As an aid to straight and level flying, gyroscopic control has been introduced. The results are remarkable. Tilts are reduced to less than half a degree, and strips are practically straight. The effect of this is greatly to increase the validity

AUTOMATIC FILM CAMERA F.8.

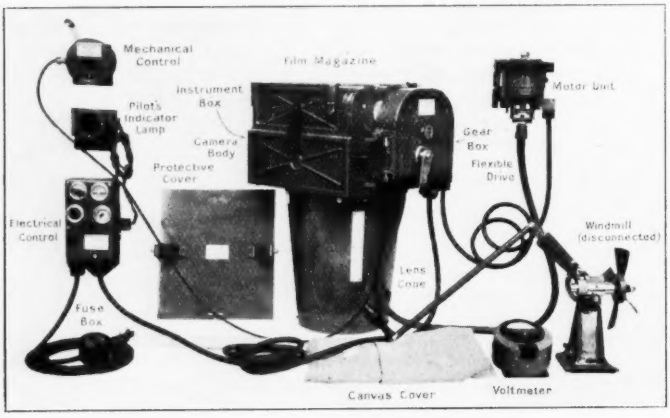


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FIG. 2.

of the assumptions made in the simplified method of plotting, and to extend its application to conditions of very scanty ground control where a solution would otherwise hardly be possible. The gyroscopic control of aircraft for air survey purposes is therefore of the highest importance, and no survey of any large area should in future be undertaken without it.

7. *Air Survey Procedure*

We are now in a position to outline a suitable procedure for embodying the above technique, and to estimate some of the quantities involved. The process may be sharply subdivided into three sections:—

(1) Air photography.
(2) Ground survey.
(3) Drawing office work.

It must be emphasised, however, that efficiency in any one section can only be achieved along with an accurate and sympathetic understanding of the work of the other two.

(1) *Air Photography.*

The procedure has been outlined above. The camera used in the R.A.F. at the moment is the Automatic Film Camera F.8, fitted with an $8\frac{1}{4}$ in. lens and taking a photograph 7 ins. square. (See Fig. 2.) When flying at 15,000 ft. the area covered by a single photograph is, therefore, about $5\frac{3}{4}$ square miles. Maintaining the normal overlaps and making a small allowance for flying cross strips and general difficulties, an estimate of about two square miles per photograph will give the number of photographs required to cover any given area, *e.g.*, for an area of 5,000 square miles arrangements should be made for dealing with about 2,500 photographs, with probably three prints of each. With suitable weather, the rate of photography when once started may be taken as about 200 square miles per hour.

To navigate the flights in the most efficient manner, a network of strips will first be flown to cover the area with a skeleton framework. This is plotted first of all, and on it are laid down the centre lines of the various strip flights required. The photographs crossed by these flight lines are used later by the pilot to check his course for the filling-in strips. In some cases existing maps may serve this purpose, but some such preliminary step should always be undertaken, or wasteful flying will be the result.

(2) *Ground Survey.*

The ground survey party should, where possible, carry out a second order triangulation, or equivalent traverse work, and, in addition, fix a number of spot-heights. These are conveniently determined by means of aneroid barometers and clinometer rays, and should number about four to the square mile. They are recorded and marked on the photographs themselves, which are mounted into albums for use in the field. With this exception the ground survey work follows normal practice. The photograph album is then sent in to the drawing office along with the other trig. data.

(3) *Drawing Office Work.*

The work of plotting from air photographs is susceptible to organisation in teams, a suitable personnel being a supervisor and six draughtsmen. With normal photography, the rate of plotting as far as the fair-drawing stage may be taken as about 10 man-hours per square mile in the case of civilised country, and considerably less when detail is less dense. Each draughtsman will require a topographical stereoscope (Barr and Stroud, see Fig. 3), and the equipment of the team will cost, in all, not more than £1,000. A problem of vital importance is the correct interpretation of the detail on the photographs, the collection of all kinds of information usefully shown on a map and the marking of names. All data of this kind should be collected by the ground party and recorded in the photograph album. To mark the names on the map, a special instrument, the photonymograph (Barr and Stroud), has been devised, by means of which the names are photographed in any desired type, and subsequently superposed upon the drawing. Taking an average name as about seven letters, the speed of this process is in all about two minutes per name. This is many times faster than hand lettering of similar quality, and can be carried out by unskilled labour.

The speed of plotting a map by these methods is considerably greater than by the ordinary ground methods, the work done is far more easily supervised, and the detail is more complete. A team, as outlined above, and allowing for all ordinary delays will turn out map material of densely detailed country at the rate of one standard 1/50,000 sheet every ten weeks.

Future Developments.

For many purposes of administration and for flying, a map on a scale not larger than 1/250,000 is required. In the normal way, however, we are forced

to take our photographs at more than ten times this scale, and the cost of flying per map sheet becomes prohibitive. A reduction of focal length merely reduces the scale of the photograph without reducing the flying; what we require is a wider-angled lens. Since the limit in this respect has for a single lens now been reached, the solution is a multi-lens camera producing a photograph equivalent to having been taken with a wide-angled single lens. Messrs. Barr and Stroud are now undertaking the construction of a seven-lens camera of this kind. Flying at 15,000 ft. above the ground, it will produce a photograph at a scale of 1/60,000 covering an area of about 100 square miles. Flying costs are therefore reduced to one-quarter, and only one-sixteenth of the number of photographs have to be handled and plotted. It is expected that by means of this camera, large areas of 1/250,000 maps may be produced which would not otherwise be possible. Such a camera has also a considerable application to the reconnaissance survey of an area to be photographed later in greater detail with the F.8 camera.

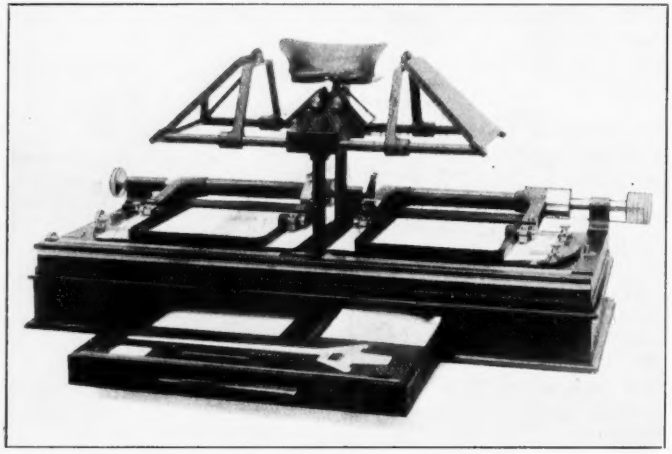

FIG. 3.
Barr and Stroud topographical stereoscope. Type Z.D.10.

8. *Imperial Survey Organisation*

Having thus briefly reviewed a practical technique of air survey, we can appreciate clearly the important contribution it offers to survey problems in the British Empire, both from the point of view of entirely new surveys and of making up the ground lost through lack of prevision. Assuming that the need for mapping is great, therefore, the question arises as to what form of administration can best carry out the aims of a given policy. Experience has shown that a private company operating by contract is not a suitable organisation, and that its deficiencies are only increased by a multiplicity of such companies. The difficulty lies not so much in organisation of the company itself as in the intermittence of demand. Similar considerations apply to small local organisations. Allowance must be made for preserving the personnel and equipment over the stagnant periods and costs are therefore higher than they need be.

The only sound organisation would seem to be one on imperial lines. The drawing and map reproduction department should be centralised, where the most skilled draughtsmen and most up-to-date equipment would always be available.

The photography necessary to keep such an establishment fully employed could be carried out by a few specially-constructed aircraft which could be flown to different parts of the Empire to make the fullest use of favourable weather conditions. The ground survey could be carried out by permanently enlisted personnel whose work would alternate between survey operations in the field and supervision at the central office. In view of the enthusiasm of the surveyor for his work, any organisation which offered him a life interest in survey and removed the fear of unemployment would be highly efficient.

The cost of survey by such an organisation is difficult to estimate, since no data exist into which various irrelevant but inseparable factors do not enter. There is no doubt, though, that the cost would be comparable to that of ordinary ground survey, probably slightly cheaper, and that when completed considerably more would have been achieved for the money. For instance, the photographs would form a basis for geological, ecological, forestry surveys, etc., and a series of maps for different development purposes could all be produced at the same time. Experience has shown that the value of air photographs in this connection is unique, since they provide accurate information which often could not be obtained in any other way. A further great advantage would be the greater speed; a survey could be carried out in two or three years which would normally take ten or fifteen. The maps would, therefore, be available sooner and their value would be correspondingly greater.

Thus far is clear, and it seems almost incredible that efforts to initiate such a scheme should not be actively sponsored. The conventional excuse is that "financial conditions do not permit"—which leads to an examination of the conditions of finance. It is obvious that if there is a human need, and there are at the same time the personnel, technique, and potential equipment necessary to supply that need, there exists a state of real credit. The function of the financial system is then to set on foot the financial credit necessary to bring vitality to this real credit. If it fails to do so, it fails to carry out the only function for which it may rightly be said to exist, and should be replaced by some system less definitely anti-social. The failure of the present system is by no means due to any difficulty in devising a better one, but lies in the vested interests of its upholders. It is useless, therefore, to devise schemes for imperial well-being without at the same time undertaking a study of the root stimuli of our existing economic system. When British people jump to the fact that real wealth is a function of the brains and energy of men and women, and has little or nothing to do with the fictitious figures so dear to the hearts of financiers, then, and only then, shall we be enabled to carry on with schemes of practical development in the Empire, and in that distant millennium it is quite certain that air survey will play its part.

Discussion

The Chairman: With further reference to the Air Survey Committee of the War Office, another of the many interests represented on it was the Colonial Office, which, of course, would be the operative Department in connection with any continuous Empire survey. In the office of the Air Survey Committee there was a remarkable map of the world, showing, by means of different intensities of colour, how the countries of the world had so far been surveyed. When he had first seen the map he had been astonished to learn how infinitesimal a part of the world had been surveyed in the way in which they were accustomed to survey Great Britain. If one painted on a map of the world the areas which had been surveyed in the manner to which they in this country were accustomed, as demonstrated in the ordinary ordnance survey maps, one would not have to use much paint; not much would be needed even for the map of such a country as the United States. He hoped that the survey of all parts of the world would in future be developed to a really high level.

An example of the remarkable developments of air survey was attached to a report issued by the Ordnance Survey Department some years ago, under the signature of Captain Hotine—who was Lieut. Salt's predecessor. It was a map of a part of the South of England, printed on tracing paper. On one side was printed the ordnance survey made by the ordinary ground methods, and on the other was printed the air survey. Both maps were contoured, the one by the older survey methods and the other by the stereoscopic method. When one held the tracing paper up to the light one could see not only that the outlines—roads, buildings, farms, etc.—coincided, but that there was very little difference indeed in the contour lines; indeed, he believed that either map would have served its purpose equally well.

With regard to developments within the last five years, the Chairman said that in the early part of that period the War Office had obtained its first Fourcade Stereogoniometer. It was purchased for his Directorate and lent to the War Office, and he had not seen it since! However, he had no doubt that good use had been made of it. Since then the "automatic pilot" had been added to the list of advances; it might well be that this advance had rendered such complicated instruments as the stereogoniometer out-of-date. The "automatic pilot" stabilised the machine, and not the camera only. It held the machine level within a degree, and it was much more clever than any human pilot had ever been either in keeping a machine level or in steering a course. It weighed a good deal less than a human pilot—about half as much—so that it did not constitute a serious addition to the weight of an aeroplane, particularly a large one, though perhaps in years to come its size and weight might be reduced, at any rate for use in the smaller machines. Perhaps that would not be easy, however, for the effort made by the pilot in controlling was not very much different as between machine and machine.

With regard to the multi-lens camera—a still newer development—one would have thought that any scheme which reduced the cost of flying by something of the order of 75 per cent., and which reduced to an even greater extent the amount of work to be done in the office, would have transformed the author's, and everybody else's, attitude to air survey work. It might be that, when photographing at 60° from the vertical, unless the ground was very flat, it was difficult to draw contours by stereoscopic relief. He asked for the author's opinion on that. The author had referred to the multi-lens camera as being one of the latest devices, and had mentioned that one was being built by Messrs. Barr and Stroud. The Air Ministry were very interested in this.

The paper contained enough material to indicate what a splendid new use lay ahead for civil aircraft. They had only just touched the fringe of air survey work. The new equipment, including the many instruments developed in Germany and Switzerland, the multi-lens camera and the gyro pilot, would enable them to make really rapid progress.

Mr. H. Hemming: He congratulated the author on a remarkably interesting paper and on having elucidated in simple but delightful language the intricacies of a highly technical problem, which, in the past, had been shrouded too frequently in a fog of technical language and of complicated formulæ. The paper impressed one entirely on its merits, but the fact that its author was the Research Officer to the Air Survey Committee rendered it all the more impressive. The Air Survey Committee, as the co-ordinating committee on air survey matters between the three fighting Services, had always adopted a most helpful attitude to those engaged seriously on commercial air survey work.

Reference had been made to the need for an Imperial survey organisation, and the author had emphasised two points which were fundamental to the success of future air surveys—(1) permanent employment for staff, and (2) the co-ordination of interests. At long last, ground and air surveys were recognised as being complementary to and not competitive with each other, and presumably

the author included in the term " surveyor " those other experts who were vital to the success of air surveys, *i.e.*, the specialist pilot and the photographer.

It should be remembered that to date most of the British air survey work, other than that carried out in Canada, had been undertaken entirely by private enterprise, and chiefly by the two British companies who were recognised by the Government and by the Air Survey Committee as being competent to do the work. Not only had these companies carried out work for Governments, industrialists and commercial organisations within the Empire, but they had also carried out contracts for foreign Governments and companies. Recently completed contracts included: (1) that of the Air Survey Co., Ltd., in which they had successfully surveyed approximately 20,000 square miles of territory in the Sudan and in Uganda, for the Egyptian Government, for irrigation purposes in connection with the waters of the Nile. This work was additional to the several successful contracts carried out by the company in India and Burma; (2) those of the Aircraft Operating Co., Ltd. in (*a*) their recently completed air survey, within a period of 18 months, of 65,000 square miles of territory for the Government of Northern Rhodesia, as well as surveys of several townships; and (*b*) their recently completed survey of Rio de Janeiro and the Federal District of Brazil.

All this work, and that of previous surveys, which had involved a very large expenditure of money by private enterprise for the creation and maintenance of specially-trained staffs and of specialised equipment and also of costly research, had been carried out without any form of subsidy or financial assistance from the British Government. That those companies had failed to keep their splendid staffs in full employment was due entirely to their inability to secure sufficient contracts. This, in turn, was due to two causes: (1) the world monetary crisis, and (2) the lack of co-ordination of interests.

The failure to keep staffs in full employment was very distressing. Personnel who had had cheerfully to undergo the hardships and worries of pioneer work, looking to the future for their reward, and who by their loyalty and keenness had made possible the success that had been achieved, are now numbered among the workless. The financier had also to be considered. This work had been accomplished in the past through far-sighted and patriotic individuals putting up the large sums of money necessary for carrying out operations and the maintenance of staff and equipment between contracts. Not only had they failed to obtain a return on their investment, but they stood to lose the considerable capital that it involved unless further contracts were forthcoming.

The other contributory cause, *i.e.*, lack of co-ordination of interests, was not only of vital importance to air surveying, but also had a considerable bearing on Empire and trade development. On November 17th last, Mr. Donald Gill had read a most interesting paper on " Aerial Survey in Relation to Economic Geology " before the Institute of Mining and Metallurgy. That paper, besides forming a very valuable contribution to the science of air survey, had dealt in a most able manner with the need for co-ordination.*

In the past, surveying had been mainly a function of Government Departments; each Dominion and Colony had its own Survey Department, and the surveyors had obtained only the data necessary to the making of maps or plans. In cases where the work of Governments had been well co-ordinated, geological and forestry surveys had been carried out in conjunction with the topographical survey. There were cases, however—and it was reported that they still existed—where, through lack of co-ordination, such surveys had been duplicated or even triplicated. That was a serious matter in these days of economic stress.

When an air survey was carried out—and it could only be carried out in co-operation with the ground surveyor—the air photographs not only provided

* Reprinted in this issue of the Journal.

the surveyor with a great deal of the data that he required for making his map, but they also recorded, for the expert who knew how to read them, valuable data relating to the economic resources of the territory photographed. In fact, air photography was one of the best co-ordinating media that had ever been invented.

In stressing the need for an Imperial organisation to carry out air survey, Lieut. Salt had fully endorsed the aims of certain proposals which were under consideration by the various Government Departments and by the Air Survey Committee, which proposals were submitted to them in October, 1932. In view of what Lieut. Salt had said, it might be of interest to quote from those proposals, as follows:—

> "Practical experience supports the chief claim put forward for air photography, that it combines in a single operation means of obtaining information on a variety of economic aspects, some of which are enumerated below:
>
> *a*. The means of providing detailed maps on a variety of scales to suit the needs of every Department of State.
> *b*. From the photographs can be derived information in sufficient detail to serve as the basis for the production of geological maps.
> *c*. In many cases they indicate localities in which mineralisation is likely to occur.
> *d*. The zones in which, as a whole, soil conditions are exceptionally favourable for agriculture as practised by (1) the European, and (2) the native.
> *e*. Zones in which forests should be reserved for commercial or protective reasons. The classification of forest growths for stocking purposes.
> *f*. In certain parts of Africa the correlation existing between the tsetse fly and climate, geology, soil, vegetation, fire, game and man.
> *g*. The rapid selection of the most suitable alignment for railways and roads, where alternative routes were possible.
> *h*. Surveys connected with water power schemes, catchment areas and irrigation.
> *i*. The survey of rivers for the improvement of navigation.
> *j*. The making of maps for town planning and improvement purposes.
> *k*. For land valuation purposes and the collection of land revenue.
>
> "From this list, which can be further extended, it will be seen that an air photo survey can find its uses in almost every branch of State activity and commercial or industrial enterprise. This is more especially the case in undeveloped and partially developed countries. Its chief field undoubtedly lies in new countries, although evidence can be shown of its usefulness in long settled countries."

The proposals then proceeded to deal in detail with these aspects. After mentioning some examples of waste due to lack of co-ordination, they continued:—

> "One of the main purposes of these proposals is to avoid such waste and overlapping by the co-ordination of all the possible connecting interests."

Having indicated a means of securing co-ordination, the proposals continued:—

> "By such co-ordination the cost of the air and photographing work would be spread over all the interests participating in the survey, because it would only be necessary to photograph the ground once.
>
> "There are to-day several opportunities for the initiation of, and contracting for, air surveys which are only held up for the lack of a businesslike and systematic co-ordination of interests."

The question of this great Imperial work being undertaken by a Government Department, continued Mr. Hemming, was at one time under consideration, but

the idea was not adopted. In any event, there were certain very definite reasons why this work should not be the function of a Government Department. Among them were :—

(1) It would be difficult for a Government Department to bring about the co-ordination of commercial people likely to be interested in the survey of an area without once committing themselves to participating in the expenditure required, as a first consideration.

(2) The British companies had, to a considerable extent, built up their experience, equipment and reputation as the result of carrying out air surveys for foreign countries. If, in future, air surveys were to be made by a Government Department, obviously it would be impossible to obtain foreign contracts.

(3) The Governmental machine, though admirable in many respects, frequently had its initiative sapped and its work slowed down through Treasury control.

It had been implied by Lieutenant Salt that the private company operating by contract was not a suitable organisation, because it could not employ its staff and equipment over the unprofitable periods between contracts. He had not stated the cause of the unprofitable periods, however. These periods had been due mainly to the world monetary crisis. Experience showed that just before the crisis arrived, air surveying was becoming profitable, and all those engaged in the work could see the fruits of their labour in sight. The cause of the trouble was the phrase referred to by Lieutenant Salt—" Financial conditions do not permit." That phrase was overdone, however, and had become a parrot cry. We could not expect to get back to normal trading by sitting still. Gilt-edged securities would cease to be gilt-edged if all the country's money were to be invested in them at the expense of getting on with constructive work. If " financial conditions do not permit," that was all the more reason why we should adopt an economic method of surveying and ensure that development work was co-ordinated with it so as to get the best possible results. If this were done, there would be no gaps between contracts, as there was enough work waiting to keep all existing surveyors and their children's children going during their lifetimes. Efficient maps of the Empire were of vital importance for successful Empire trading and development.

There was no need to replace the existing companies by an Imperial organisation. An Imperial organisation should be formed to ensure that we in the Empire led the world in air survey work, and, as the two companies had valuable staffs, equipment and experience, and much goodwill, such an organisation should help them to get more work, so that an Imperial air survey service could be built up.

In the proposals referred to earlier such an organisation was suggested, and was called an association, but it was not intended that it should carry out air survey operations itself. The idea is that the association would have a governing body of well known and influential people, and also an advisory technical committee made up of experts representative of the different branches of economic development, including representatives of the Air Survey Committee and of Government Departments, as well as of representatives of the operating companies concerned with air survey.

The association would not control air survey operations in any way. Its main aim would be to secure the co-ordination of Government Departments and private enterprise for the carrying out of air surveys, and to ensure that the services that air surveying could offer to Empire and trade development were made full use of.

It was not proposed that the association should be profit-earning. A scheme of finance had been evolved which should enable it to carry out its aims, without

financial support from the operating companies. The Government had not been asked for financial support in any shape or form.

The proposals were still under consideration, and would not have been made public at this stage had not Lieutenant Salt referred to, and so strongly emphasised the need for, an Imperial organisation. Lieutenant Salt had certainly furthered the cause of air survey by his paper, and had helped to revive hopes that perhaps before long the operating companies would be able to take back into employment those splendid fellows who had done so much to make these surveys, carried out by British personnel, the best in the world.

The last paragraph of Lieutenant Salt's paper extended beyond the subject dealt with, and made most able reference to the fundamental cause of the world's troubles to-day, *i.e.*, the breakdown of the financial system. Unless something were done to rectify that fairly soon, so as to release funds for sound development work, in order to revive trade and create employment, they would be faced with a state of affairs too terrible to contemplate.

Finally, Mr. Hemming emphasised that he would prefer to see the work of Empire survey carried out by an Imperial organisation independent of Government control, rather than under the control of a Government Department. The main thing, however, was to ensure that the valuable services that air survey could render to Empire and trade development were fully used, and the paper should do much to help in that direction.

Mr. Donald Gill: He spoke as a mining engineer and therefore a potential user of air surveys. In order to develop the Empire, of course, they must have air surveys, and an Empire organisation for survey purposes was extremely desirable, but if the proposed organisation were to be a Government Department he was afraid that commercial interests who needed air surveys would not be able to get them rapidly and easily, owing to red tape, and so on, unless the areas they wished to have surveyed happened to be within areas which were being surveyed in any case. During the last few years an enormous amount of surveying had been done from the air by commercial interests. For example, in Mexico, California and Texas, within the last few years, at least 30,000 square miles had been surveyed from the air on behalf of the oil companies, and the surveys had been made use of by the oil companies' surveyors and engineers. In Northern Rhodesia, Mr. Hemming's Company had surveyed 10,000 square miles for a copper exploiting company. The value of air surveys was only just beginning to be appreciated by commercial people, and he feared that if the proposed Empire organisation were purely a Government Department the commercial interests would be left out in the cold; the present-day survey companies would cease to exist, and people who wanted small or moderate size areas surveyed would not have the facilities at their disposal.

Brigadier Winterbotham (Director-General, Ordnance Survey): In his first paragraph Lieutenant Salt is a little over-confident in stating that in nearly every country the initiative in survey matters has been taken by the Army. Large scale survey for property purposes has been practised since the very earliest recorded times of history. Property surveying supplies the key to most of the surveying which goes on at present. It is, however, true that the initiative in topographical surveying, and in those geodetic and other triangulations upon which all surveys should be based, has almost invariably been taken by soldiers.

There is great need for thought and development in bringing to the public service the speed of well-organised air surveys. As a case it is, however, spoilt in this and other papers by the omission of any reference to good surveying on the ground. A classic example may be quoted. The triangulation and topographical survey for a half-inch series has been carried out at a lesser cost than 8s. per square mile. Each member of the party supplied about 1,500 square miles completed map per annum.

For the tropical dependencies there are two possibilities, and one thinks two only. One is by Lieut. Salt's suggested organisation of air surveys; and the other, cheaper, as efficient, but taking longer in time, is the use of a well-trained African staff. These two methods are not mutually antagonistic, neither is there any reason to insist upon one at the expense of the other. Both will be found useful, and their utilities will be found complementary and not competitive.

Flight Lieutenant BUSSEY: He emphasised the importance of weather conditions upon survey work. It was often assumed, he said, that, given an aeroplane and a camera, they could produce aerial photographs as easily as putting a shilling into a slot. The taking of photographs from aircraft at a height of 15,000ft., however, was literally dependent upon the weather, and that factor should be very clearly borne in mind when considering air surveys.

As the photographs can only be obtained when the weather will permit, it will often be necessary to plan a survey a long way ahead; and probably, on many occasions, the photographs will be taken during a period of suitable weather many months before the actual mapping is undertaken.

Mr. F. L. WILLS (Aerofilms, Ltd.): During a recent visit to Germany, he had had an opportunity of seeing the scientific survey apparatus made there; the new multi-lens camera, which Lieut. Salt had referred to for possible use with Capt. Hotine's principle, was also of great interest. He agreed with Mr. Hemming that the proposed survey organisation should be on a commercial basis; otherwise they would not be able to compete for the surveying of other countries outside the Empire.

THE CHAIRMAN: Bearing in mind the author's reference to a railway on the Gold Coast which was built without a preliminary survey having been made, and which had cost £1,500,000 more than it need have done, he assumed that that kind of thing did not occur in modern times, and he asked if Major Williams, as a representative of the Crown Colonies, could give an assurance that the railways under his control were all built after survey, either from the air or otherwise.

Major WILLIAMS: The survey of the Gold Coast Railway was carried out even before his time. He had nothing more to add with regard to it.

REPLY TO DISCUSSION

Lieutenant SALT prefaced his reply by drawing attention to the great assistance given to the development of air survey by the enterprise of private firms. Messrs. Williamson had been responsible for many improvements in camera design, and as a result of efforts to produce a suitable shutter for this type of work had evolved a louvre shutter which considerably reduced the distortion inherent in a focal plane shutter. Messrs. Williamson had been kind enough to provide an Eagle Mark III camera (the civilian edition of the F.24), with complete electrical equipment, for demonstration at the meeting.

With regard to instruments for the plotting of air survey photographs, Messrs. Barr and Stroud had done most of the pioneer work and had been remarkably successful. Mr. Hasselkus had been too modest to say anything about the work of Messrs. Ross, but it was largely due to their enterprise and initiative in producing new types of lenses that such developments as the multi-lens camera were made possible.

Though Mr. Hemming had said much that he himself had intended to say, he could not agree with all Mr. Hemming's remarks. The point about surveying in foreign countries might be sound from the philanthropic point of view, but it savoured suspiciously of that well-worn fallacy "the favourable balance of trade." It was surely better to survey our own Empire first.

Mr. Gill expressed doubts as to the efficiency of an organisation run by Government. He would like Mr. Gill to distinguish between policy and administration. Government administration was much the same as any other form of administration; policy, however, rested ultimately always with finance. He had tried to indicate how modern financial policy had little relation to physical facts. Canada offered a good example of a Government-administered topographical survey. Some 400,000 square miles had been photographed in the last ten years (last year alone, the area was over three-quarters the size of Great Britain), and a Photographic Library had been established, containing 560,000 prints. All were tabulated, and ready reference to them could be made by anyone. As an example of its value, no hydro-electric work had been undertaken in recent years in Canada without reference to that library.

Commenting on the fear expressed that the survey companies might die if they were not given support, he suggested that they were already practically dead, and under the existing economic system would remain so. He did not think there was the slightest hope of carrying out surveys on those lines without radical reform and a subservience of financial policy to national interests. Mr. Hemming's proposals were a plea to revive a spark of life in an old corpse; what we needed, however, was a completely new child. The sooner we started to face facts the better.

AERIAL SURVEY IN RELATION TO ECONOMIC GEOLOGY*

BY

DONALD GILL

1. General

Introductory.—The great interest being taken at present in the use of aeroplanes in connection with mining, shown in the reception given to a recent paper before the Institution[1], has suggested to the author that a paper may be welcomed which deals with aerial survey as an aid to the geologist and to the prospector, and which attempts to put before members information on the subject, much of which is available but not altogether accessible.

The objects of the present paper are:—

(1) To deal with those aspects of the technical side of aerial survey which are most likely to concern the geologist, and of which he should have some knowledge before undertaking to employ aerial survey;
(2) To discuss the use and interpretation of aerial photographs by the geologist;
(3) To advance some tentative conclusions regarding the conditions which are necessary to enable geological inferences to be made from the air;
(4) To present a full bibliography, in order that members may consult original sources of information where desirable; and finally
(5) to promote discussion.

Photographs taken from an aeroplane are commonly known as "aerial photographs." The application of aerial photographs to the preparation of maps (or of mosaics) is commonly known as "aerial survey" or "aerial surveying." Similarly, it is proposed that the use of the aeroplane in geological mapping or reconnaissance (whether by photography or by visual reconnaissance) shall be known as "aerial geology."

Aerial survey specialists are nowadays careful to explain that aerial survey does not, and cannot, supplant the surveyor on the ground, but that aerial survey gives the ground surveyor a new tool that can be used with great advantage, in some circumstances to speed up his work, and in some respects to improve the quality of his work.

In the same way, aerial geology can never supplant the work of the geologist on the ground; work on the ground and from the air must always be carried on in conjunction. But those who have had experience in the practice of aerial geology claim that, by its use, work on the ground may be materially speeded up[2] (28, 45, 48, 51, 52 and others) and often improved in quality (48); and that it may give access to geological information otherwise difficult or even impossible to obtain (25, 43, 44, 48, 51, 52, 56, 58, 123 and others). Aerial geology, therefore, is to be regarded as a tool at the disposal of the ordinary geologist and *not* as something exotic and distinct from ordinary geological practice.

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* Paper read before the Institution of Mining and Metallurgy, November 17th, 1932, and reprinted by kind permission of the Institution. The paper has been slightly abbreviated.

[1] "Air Transportation of Gold Dredges in New Guinea," by C. A. Banks, *Bulletin* No. 334, I.M.M., July, 1932.

[2] Figures in brackets are references to the bibliography at the end of the paper.

Bibliography.—The bibliography contains all the references that the author has been able to find bearing on aerial survey, aerial geology and cognate subjects, *that are likely to be of interest to the geologist.* A short summary or indication of subject-matter has been given for most references; those in which it is lacking have mostly been unobtainable in London.

History.—Until the beginning of the late war few aerial photographs had been taken, and they had been regarded as having exclusively military utility. The mathematics of photographic surveying had, however, been worked out.

During the war, both the aeroplane and the art of aerial photography were developed at an amazing rate. Even in 1916 aerial photographs were being circulated to heavy artillery brigades engaged in counter-battery work, and before the end of the war regimental officers of all arms were being supplied with large numbers of aerial photographs of the enemy positions in front of them. From about 1917 onward, the Geographical Section, General Staff, was producing corrected maps of Northern France from aerial photographs, fitted to instrumental ground control. In the later stages of the war, inferences made from the careful routine examination of aerial photographs, taken over the trench systems and behind the lines, were relied upon to give most valuable intelligence of intended future movements of the enemy. Since the close of the war, aerial survey has developed on commercial lines, and very large areas—amounting in the aggregate to hundreds of thousands of square miles—have been mapped in many countries, including Canada, U.S.A., Iraq, Egypt, India and Burma, Northern Rhodesia, and elsewhere. Increasing use is being made of aerial survey for town-planning, for the control of big engineering projects, and for scientific investigations connected with soils, forests and geology.

The first reference to aerial geology was probably made by Lee in " The Face of the Earth as seen from the Air " (21) published in 1922, in which he states:—

> " It is of interest that Col. A. H. Brooks, who was chief geologist to the American Expeditionary Forces in France during the war, found that geologic boundaries could be recognised on air photographs and that by means of these photographs he could correct existing geologic maps and identify formations in inaccessible areas within the enemy lines. His method was to use photographs in the study of geologic formations of areas accessible to him. Then, having familiarised himself with the appearance of the different rock formations and structures on the photographs, he was able to recognise the same features on photographs of areas held by the enemy, and so project his mapping over into inaccessible country. . . . "

In 1925 M. R. Campbell and Edward Sampson, of the U.S.G.S., were successful in mapping geology on aerial mosaics assembled from aerial photographs, and a paper was read on the subject (22 and 112). In California, aerial photographs became of increasing importance in oil-geology from about 1926 onwards (43, 44), and since that year a great number of descriptive articles on the subject has appeared in the technical press of the American oil industry. (Bibliography, Section 3.) During 1928, it was recorded that practice was beginning to become standardised as a result of experience gained in the use of aerial maps for geological study covering over 5,000 square miles in the previous year (48) and that results indicated that the use of aerial photographs in oil-geology was likely to become routine (45).

In Canada, C. Maclaurin suggested in an article in 1922 that the aeroplane could be used in geological reconnaissance (71). The aeroplane first came into use on a large scale in connection with prospecting for minerals in the Red Lake area of Ontario, and the Rouyn field of Quebec, largely for transport, but prospectors and geologists flying over the country quickly found that the " aerial view " was of great assistance in their ground work (82). In 1929, in Canada, three large prospecting companies explored nearly 200,000 square miles with the aid of aircraft communications, their machines flying an aggregate of over 500,000 miles (81). The purely geologic side of this use of the aeroplane was probably subsidiary to the " supply and transport " side, but still was important. For

the past eight years the Canadian Geological Survey has been making increasing use of flights in aeroplanes for the purpose of observational reconnaissance, and they are finding aerial photographs to be of very considerable value as a source of geological information.[3] In 1929 the Royal Canadian Air Force did 153 hours' flying, and took 3,246 photographs for the account of the Geological Survey (81).

In 1926, Rhodesia Congo-Border Concession, Ltd., decided to survey from the air a great part of their concession in Northern Rhodesia, and, so far as can be gathered (119), the decision to do so was based partly upon the hope of spotting the " mineral dambos " that were expected to accompany the outcrops of all the copper orebodies of the region. For various reasons this hope was not fulfilled, but the survey, which was carried out in 1927 (120), resulted in the production of an excellent reconnaissance map covering about 10,000 square miles that cannot have failed to assist materially in the prospecting of the part of the concession covered. More recent work tends to show that Northern Rhodesia is not an entirely hopeless terrain for the practice of aerial geology and that it may be possible to interpret geological structure there from aerial photographs and ground work on joint ecological and geological lines (91). The aerial photographs in Northern Rhodesia certainly give ready access to some kinds of geological information much more easily than it can be obtained on the ground.

The French, especially in Morocco, have practised aerial geology (26, 124), and it has proved useful in the oilfields of South America (Venezuela and Colombia), Mexico (Tampico-Tuxpam), New Guinea, Borneo, East Indies (25), and in Australia (116, 117, 128).

During the past few months, aerial surveys have been made over mining ground in South Africa at the Consort Mine near Barberton and in the Rooiberg tin-field, and it is understood that 600 square miles are to be photographed on the Rand in order to " obtain an entirely new insight into the geological peculiarities of the Witwatersrand and to establish links between formations in broken country which have hitherto escaped the prospector's eye."[4]

2. The Technical Side of Aerial Survey as it Concerns the Geologist

Aerial photography is such a highly technical and specialised business that it is almost impossible for the geologist to get any results himself—even if he can get hold of the equipment—and in practice it is always entrusted to specialists, who may be either a commercial company or the photographic section of an Air Force. The latter can, of course, only be employed by Governmental Geological Surveys.

Nevertheless, it is highly desirable that the geologist contemplating the employment of aerial survey should have fairly clear ideas upon its technical side, otherwise it is difficult for him to specify what he wants or to appreciate the effect of specifications proposed to him. The position is somewhat similar to that of the ordinary geologist wishing to employ the more difficult geophysical methods; he has not the experience, the mathematics, or the material to carry the job to a successful issue, but it is necessary for him to have a fairly clear appreciation of what is involved in order to keep his end up with the specialist who will be employed.

In the following, the author has endeavoured to present the technical side of aerial survey only in those aspects which concern the geologist.

Photography

Aerial photographs may be divided into two classes: Verticals and Obliques.

[3] Director, Geological Survey of Canada, personal communication.
[4] *Mining Magazine*, Johannesburg correspondence, August, 1932.

Verticals are taken with the axis of the camera pointing vertically downward, as near as maybe; obliques are taken with the camera axis at a low angle with the horizontal, and, if they are required as survey data, and not merely as pictures, the horizon must appear in the upper portion of the field in order to give a datum from which the angle of depression of the camera axis can be determined.

Cameras.—The aircraft camera, of which it is not proposed to give any detailed description, is mounted in such a manner as to neutralise engine vibration and to permit the camera to be levelled relative to the aeroplane and to be turned in azimuth relative to the aeroplane, in order to correct for drift or " crabbing." In order to fix accurately the distance between the film and the rear nodal point of the lens, and to keep the film flat, the camera body is made of metal and there is a glass plate in the focal plane, against which the film is held with a pressure-pad. This glass plate is further used to fix the " principal point " of the photograph (the intersection of the axis of the lens with the film), either by reference marks at the edges of the field or by a small cross at the principal point; these marks are photographed at each exposure. Film, in rolls sufficient for about 100 exposures, is carried in magazines, which can be changed during flight as they are exposed.

The operation of most cameras for survey work is fully automatic—that is, exposures are made at predetermined time-intervals to get the correct overlap between photographs, and film is wound automatically between exposures. In most aircraft cameras there is a set of subsidiary lenses which photograph a group of instruments at each exposure, and so provide in the margin of each photograph a record of the conditions under which it was taken. The most important of these instruments are:—

(1) A click-counter, giving the serial number of the photo.
(2) A watch, with second hand, giving the exact moment of exposure.
(3) An altimeter, showing the variation of the aeroplane from standard height.
(4) A small plaque giving the name of the survey, the date, the focal length and aperture of the lens, the type of ray filter being used, the height at which the aeroplane is to fly, and the names of the pilot and photographer; in some cases only part of this information is given.

Formerly a pair of level-bubbles and a compass were included by some; both these instruments are nearly useless and are now seldom seen. The level-bubbles are affected by centrifugal force if the aeroplane banks, and the compass is generally useless owing to the employment of solenoids in the camera for automatic operation. The other information is of the greatest use in the examination of aerial photographs when large numbers of them are involved, *and it should always be specified that contact prints be delivered with this information intact.*

Lenses.—" Aero " lenses are available in focal lengths ranging from 6in. to 20in. In vertical photographs the scale of the photograph is expressed by focal length of lens divided by height (both in the same units) and variations in scale are obtained by variations in height flown and focal length of lens used. Thus a 7-in. lens flown at a height of 11,666ft. will give a scale of 1 : 20,000, while a 20-in. lens flown at 8,333ft. will give a scale of 1 : 5,000.

Films and Filters.—Film used must be fine grained, in order to give good resolution of detail. This is especially important for geological work. Film must be panchromatic in order to allow of the filtering-out of the rays at the blue end of the spectrum to counteract haze. Atmospheric haze (moisture haze) disperses the sun's rays at the blue end of the spectrum, in part, causing them to reach the eye from all parts of the sky and thus causing the blue colour of the sky. Part of the blue light so dispersed reaches the lens of an aerial camera, after a change of direction which may amount to nearly 180°, and causes fogging if no filter is used to absorb it. The higher the aeroplane,

the more fogging and the heavier the filter that has to be used. Fogging which makes it impossible to take " unfiltered " photographs occurs even under conditions giving excellent visual observation from the air; part of it, though described as " blue," is due to the ultra-violet range of the spectrum. A choice of various densities of filters is available for use under varied conditions.

The use of the new " infra-red " photography would be very attractive for some classes of geological work, since it would enable differentiation of soil colours which now register in the same tone, and so allow of the tracing of bedding with greater facility. Its use has been barred for vertical photography owing to the rather long exposure required, but experiments are now being carried out near London by the Air Survey Co., and it is understood that the results are encouraging.

Scales.—The range of scales available for vertical photography is limited by the following considerations:—

(1) Standard fields in British aircraft cameras are 5in. × 4in. and 7in. × 7in. For all scientific interpretation, where it is desirable to have large areas appearing on each photograph, *7-in. × 7-in. photographs should always be specified.*

(2) With a 7-in. × 7-in. field, the shortest focal-length lens that will cover with satisfactory definition and lack of distortion in the corners of the field is the 7-in. Ross wide-angle lens, but this lens requires very good light conditions if unequal illumination of the field is to be avoided. For all-round use the employment of an 8-in. lens may be safer.

(3) Commercial photography is probably limited to a ceiling of 18,000ft. above sea level (owing to ceiling of aeroplane, to intense cold and to lack of oxygen, work at greater heights would involve the provision of special machines and oxygen breathing apparatus). In a plateau country with an elevation of 5,000ft. the effective photographic height is thus reduced to 13,000ft.

(4) In the direction of the small scales, therefore, there is a practical limit with the 8-in. lens of about 1 : 27,000 over country at sea level, and 1 : 19,500 over country at 5,000ft. If the 7-in. lens can be used, the limiting scales are 1 : 31,000 and 1 : 22,500 respectively. If the work is done with a light aeroplane, the limiting scales will be larger and controlled by its ceiling.

(5) In the direction of the large scales, minimum flying height for vertical photography might be put at 4,000ft. over the country being photographed; with a 20-in. lens this gives a scale of 1 : 2,400, but at this height and scale topographic displacement would be very great (see section on geometry) and satisfactory mosaicing would be difficult to obtain in anything except dead-flat country.

Overlap.—Photographs are taken at such time intervals that each photograph overlaps the previous one. Both for survey purposes and for stereoscopic examination of photographs it is necessary that this overlap should exceed 50 per cent., in order to ensure that each point of detail in the country appear on at least two photographs. For " Arundel " traversing it is necessary that certain points of detail appear on at least three successive photographs, and 60 per cent. overlap is required.[5] *This amount is also very satisfactory for stereoscopic examination and should always be specified in geological work*, even if the photographs are not needed for mapping.

Flying

Country is covered by flying a series of parallel strips. In the case of vertical

[5] The " Arundel " method of surveying from aerial photographs is fully described in No. 16 of the bibliography, and cannot be dealt with here.

photography, it has already been mentioned that the individual photographs in each strip overlap one another by 60 per cent. The strips themselves overlap, by an amount which may average 25 per cent., this overlap being chiefly an insurance against uncovered gaps, which are usually expensive to fill. In important surveys the overlap of the strips may be increased to over 50 per cent. in order to allow of stereoscopic study of the ground in two directions at right-angles. In oblique photography, the country is still flown in strips and the practice is usually to take the photographs in sequences of one to the left, one along the strip (fore or aft) and one to the right, every point in the country being covered several times.

Tilt.—Survey flying demands a great deal of natural aptitude on the part of the pilot, coupled with experience, and good co-operation between the pilot and the photographer as a team. The subject is dealt with in detail elsewhere (15). It may be well, however, to point out that the client is completely in the hands of the specialists when it comes to obtaining photographs of uniform scale and as free as possible from tilt. There is no means of ensuring the absolute verticality of the axis of the aircraft camera, and the client has to rely upon the reputation of the firm for doing good work.

The problem for the pilot is to fly his aeroplane straight, level, at a uniform height, along the desired course on the ground and at a uniform ground speed—usually over unknown country—and with corrections to make for drift. Changes of trim by the pilot necessitate re-levelling of the camera by the photographer, but the mere fact of changing trim (especially turning) involves centrifugal forces on the level-bubbles of the camera which make them unreliable as indicators of level.

In mapping and mosaicing work excessive tilts, say over 5°, introduce difficulties which depend upon the uncertainty of the amount and direction of the tilt. No method has yet been perfected of registering the amount and direction of tilt directly upon the photograph.

For purely geological inferences from photographs, moderate tilts are not detrimental, since the photographs for this purpose are merely pictures.

Developing, Printing, etc.

These are large-scale commercial photographic operations which do not much concern the client. A few points, however, deserve notice. The first is the provision of a supply of clear, *cold* water for darkroom operations. In the event of the survey being done far from the headquarters of the photographic section or company, the client may be called upon to find suitable water—and under some tropical conditions it may be difficult to do so. Another practical point is the importance of developing negatives and printing contact prints in the field as soon after photography as possible. These prints are needed by the photographers and pilots to ensure that the whole area has been properly covered without gaps, and they are equally wanted as early as possible by the geologist for field use.

" Contact prints " are made with the negative and the printing paper in direct contact, and they therefore give neither more nor less detail than appears in the negative, whereas enlargements or reductions printed in a lantern can often improve the tone, or, conversely, disimprove detail. For the geologist contact prints are the best to use for interpretation, and they have the advantages of being easy to handle in the field and of being cheap and quickly obtainable. The author's preference is for prints on the surface known as " ivory-matte."

Aerial photographs can be enlarged to about twice the linear dimensions of the negatives without losing very much definition, and for the purpose of making mosaics they can be printed in special rectifying printers which rid them of scale distortion due to tilt and in which the scale as a whole can be modified as desired either in the direction of reduction or enlargement.

Quality of Photography

In order to permit of scientific inferences being made from photographs, the quality of the photography must be the highest that can be got. Many geological inferences depend upon quite slight changes in colour (tone) and texture. Photographs must have excellent definition and they should not be " flat," rather tending toward contrast.

Many aerial photographs have accidental defects, and it should be the aim of specialists to eliminate them. Some of these defects may be of no great moment for survey photographs, but for geological work they are most fatiguing to the eyes, tend to distract the attention from what is being sought, and make stereoscopic fusion more difficult. The following may be mentioned:—

(1) Scratches, parallel with the direction of motion of the film in the camera.
(2) Alternate bars of lighter and darker printing, or a falling off of the tone of prints toward the corners, due to bad distribution of light in the printing machine, or to unequal illumination of the field of the negative by the camera lens respectively.
(3) Patches of poor definition on prints, due to unequal contact of the film and paper in printing.
(4) " Static " marks.
(5) Marks due to dust.

Time of Day for Photography

Nothing can be laid down with any definiteness, but it is true that for each job there are conditions of light that will enable the maximum of geological inferences to be made from photographs.

For example, in a country of high hills and steep slopes it may be essential to photograph as near mid-day as possible, in order to minimise very deep shadows. " For bedding, shadows are a disadvantage, minor features being lost on the photos in the dark spots representing shadows " (58). In very flat country, however, it may be desirable to photograph with the sun low, in order to bring out such relief as there is, but, generally speaking, long shadows (*e.g.*, from trees in a forest) are detrimental to good geological interpretation.

In certain soft Tertiary sediments in the San Joaquin valley, California, geologic structure was scarcely apparent until it was revealed by aerial photography in just the right light to reveal every minute irregularity of the surface, and, as a result of this photography, some very remarkable well-locations were made.[6]

In many instances there may be no choice but to do photography at a time of day selected by the aerial survey specialists on technical grounds involving the quality of the light, the weather, etc. It may be laid down as a general principle, however, that the whole survey should be done, as far as possible, under similar light conditions (*i.e.*, morning, noon, or evening), since shadows falling in different directions on different strips of photography are very confusing, especially in mosaics.

Time of Year for Photography

The best time of year for doing photography *may* be fixed entirely by local climate. In those countries which have grass fires in the dry season the smoke interferes very greatly with photography and hangs about until the first rains. In some countries clouds may prohibit commercial photography altogether at certain times of the year.

Where there is any choice, the type of information that is sought from the photographs may influence the time of year selected. For example, in a heavily-

[6] Director, U.S.G.S., personal communication.

vegetated country the forest may obscure information sought on the ground except in autumn or winter. On the other hand, the vegetation itself may afford clues to geological boundaries, and then it would be preferable to photograph at the time of year at which different types of trees show the greatest differentiation in colour or texture, probably late spring (but possibly autumn in Europe).

Index Maps

For any survey exceeding a few prints, an index map should be delivered to the client with the photographs. This should consist of a plan of all the strips flown, showing the approximate plumb-points of the photographs with their serial numbers. In the case of very long strips it is not necessary to indicate every photograph, so long as it is possible to locate it approximately by interpolation. The map should indicate also points of ground control and the leading features of the drainage, etc. Where a mosaic of the area is being made, the index map may consist of a reduced copy of the mosaic upon which the special information is posted in white and the whole re-photographed. As many copies as are needed can then be printed off.

Contact prints are best filed in loose-leaf binders, each binder containing an extract from the index map showing the numbers of the strips corresponding to the prints in the binder.

The Geometry of Aerial Survey

It is impossible here to do more than bring forward a few elementary points regarding aerial survey geometry. The subject is dealt with very fully in various references listed in Section I of the bibliography, and especially in the excellent Professional Papers of the Air Survey Committee. All that the geologist needs

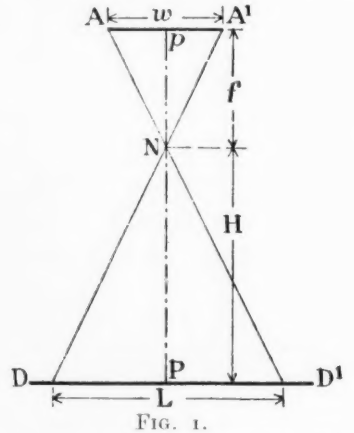

FIG. 1.

Relation between scale, focal length and height.

to appreciate quantitatively is the relationship between scale, focal length of lens, and height of aeroplane, and the difference between a vertical photograph and a map; while qualitatively he should know of the effects of tilt.

In Fig. 1, AA^1 is a photographic film of width w mounted in a camera, the axis of which is vertical, and having a lens of focal length f, of which **N** is the nodal point. The lens is at height H above the datum plane DD^1 of the map. AA^1 and DD^1 are taken to be perpendicular to the plane of the paper, which passes through the " principal point " p of the photograph and the " plumb

point " P of the aeroplane camera. The photograph of the plumb point of the aeroplane will coincide with the principal point of the photograph. The length, L, of ground appearing in the photograph will be related to w, f and H, and to the scale of the photograph, according to the simple equations:—

$$\text{Scale (expressed as a fraction)} = \frac{f}{H} = \frac{w}{L}$$

This relationship is quite clear from the consideration of similar triangles and needs no elaborate proof.

The ideal conditions of Fig. 1 are, however, seldom realised on account of two facts: (1) that the ground in the photograph is seldom dead flat, and (2) that it is impossible to guarantee the absolute verticality of the axis of the camera.

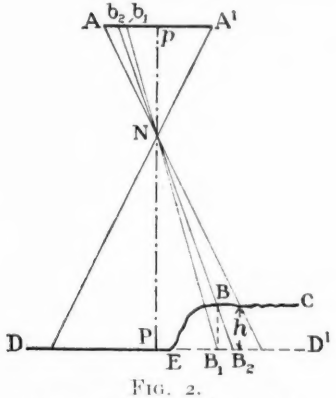

FIG. 2.
Topographic displacement.

Topographic Displacement.—In Fig. 2, with similar notation, the plate or film is still assumed horizontal (*i.e.*, the camera axis is vertical). The country photographed, DEBC, lies partly in the datum plane of the map and partly above it. Point B, at height h above the datum plane, will appear on the negative at b_2, *as though it were situated in the datum plane at* B_2. If the aerial photograph were a map, point B would appear on the map at b_1, as though situated in the datum plane at B_1, the vertical projection of B. The distance B_1 B_2, is known as the *topographic displacement* of point B, due to its height above datum. From consideration of similar triangles, it is evident that B_1B_2 equals $\frac{h}{H}$ PB_2. This is the apparent displacement of point B on the ground. Its actual displacement on the negative, b_1b_2, will be its apparent displacement on the ground multiplied by the scale of the photograph, or $(fh/H_2)PB_2$. It can, of course, be just as easily shown that a point situated *below* datum will be displaced by a similar amount *toward* the principal point of the photograph.

This radial displacement of points—outward or inward, away from or toward the principal point, according as they are above or below the datum plane—constitutes the only serious difference between an aerial photograph and a map, *at least so far as the geologist is concerned.* Once this has been grasped, it is not difficult to perceive the following consequences:—

(1) All azimuths in the photograph *which pass through the principal point* are correct.

(2) All azimuths in the photograph *between two points at the same height above datum* are correct.

(3) All other azimuths in the photograph are in error.

(4) The " map " position of any point on the photograph may be found if the height of the point above datum is known.

(5) In making up a " mosaic " of aerial photographs in mountainous country, the top of a mountain situated at a join will be displaced in different directions on the two photographs and there will be an error of " match "; this error can be reduced as much as we please by increasing the overlap between photographs, and using only the portions of each photograph near the plumb point for the mosaic (but at increased cost for photography).

(6) The " scale " of elevated parts of the photograph, *e.g.*, plateaux above datum, will be greater than the standard scale of the photograph in the proportion $H/(H—h)$; this can only be corrected on a mosaic by specially-rectified printing of parts of photographs (and then only by rule of thumb, in the absence of close ground control).

Consequence (1) is used in the " Arundel " method of triangulation from aerial photographs. Consequences (1) to (4) are used in the employment of enlarged aerial photographs as plane-table sheets (see below).

Effects of Tilt.—In the whole of the foregoing it has been assumed that the axis of the camera was vertical at the moment of exposure, and (in consequence) that the principal point of the photograph coincided with the photograph of the plumb point of the camera on the ground. In reality all " vertical " photographs are slightly tilted.

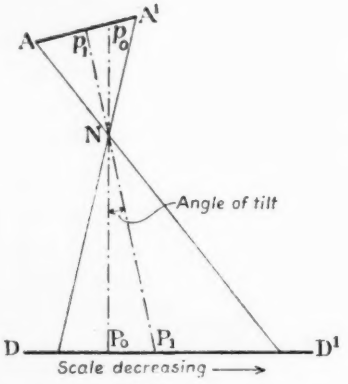

FIG. 3.

Effect of tilt in displacing plumb-point and in varying scale.

Fig. 3, with similar notation to Figs. 1 and 2, shows qualitatively the effect of tilt, in displacing the plumb point from the principal point of the photograph. P_0 and p_0 are the plumb point and its photograph, while p_1 is the principal point of the photograph and P_1, the point on the ground corresponding to it on the photograph. This figure also shows the way in which the scale of the photograph progressively decreases across the field of the photograph.

It is impossible here to consider geometrically all the effects of tilt. For *small-scale* mapping purposes it has been determined that, providing the tilt is small (not exceeding 2 to 3°), and providing the differences of elevation in the ground photographed do not exceed one-tenth the height of the aeroplane above datum, the principal point of the photograph can be used for azimuths *as though it were the plumb point* without appreciable error.

Mapping from Aerial Photographs.—It is impossible here to deal adequately with mapping, and members are referred to Section I of the bibliography; the subject is of no *direct* concern to the geologist.

Mosaics.—A mosaic is an approximation to a map, built up on a backing of some sort (plywood, for example) by sticking on it the central portions of a number of photographs and getting them to " match " as well as the amount of ground control, the differences of elevation in the country, and the permitted cost of the work will allow. The completed mosaic is re-photographed in sections of convenient size and as many copies as are required can be printed off. The degree of " control " in a mosaic can vary from nil in a rough " stuck-down " mosaic made simply by " matching detail " to the provision of a number of surveyed points on each photograph.

Increasing approximation to a true map is obtained in mosaicing by the use of the following devices:—

(1) Decrease of topographic displacement by increasing the overlap between photographs in all directions and using only those parts of photographs quite near the plumb points.

(2) The rectification of photographs, or parts of photographs, by printing them in a rectifying printer to correct for slight differences in scale and to eliminate partially the scale distortion due to tilt.

(3) In conjunction with (2), closer spacing of ground control and/or carrying out " Arundel " triangulations over strips of photographs between points of ground control (16).

The exact methods used in a given case will depend upon circumstances; *it is very largely a question of cost, which begins to rise sharply as control is introduced.*

The following points are of practical interest to the geologist and deserve to be specially noted:—

(1) It is desirable that all the photographs in a mosaic should have been taken at approximately the same time of day, to avoid confusion in shadow effects.

(2) It is very highly desirable that all " joins " should be bold, straight knife-cuts, rather than that they should be camouflaged by being made to follow some undulating feature (*e.g.*, a road, the edge of a forest, a stream) on the ground, as is done in making " pretty-pretty " mosaics. It should be impossible to mistake a join for anything *but* a join in mosaics used for scientific purposes.

(3) It is preferable that there should be a frank break in detail at a join than that matching should be " fudged " in any way (*e.g.*, by stretching the emulsion of the print when wet).

Mosaics are very useful in giving the geologist a wide view of large areas of country, and yet, with this wide view, combining a wealth of detail that cannot otherwise be obtained. However, for many types of geological investigation it is a question whether a mosaic (as an addition to a set of contact prints and an index map) justifies its cost. The question must be left open for decision in each case, remembering that the making of a controlled mosaic may triple the cost of the survey. The contact prints and the index map are needed in any case and they are very quickly available; mosaicing is somewhat slow work and the delivery of a mosaic may occupy many weeks after the completion of photography.

* * * * *

In closing this short review of the technical side of aerial survey the author again wishes to emphasise that the intention has not been to make it exhaustive, but merely to draw the attention of geologists to those aspects which concern them directly.

In so condensed a description of a highly-technical subject it is likely that certain statements may appear inaccurate, or even misleading, to specialists in that subject; members are referred to the first section of the bibliography for authoritative information.

3. The Cost of Aerial Survey

It is impossible to give "average" figures for the cost per square mile of aerial survey with any pretence of reliability, and the cost for any area can only be worked out if the fullest particulars of the size of the area, the local conditions, and the precise service required, are known.

The reasons for this state of affairs are numerous, and a few of them can be shortly dealt with. *First*, the "overhead" cost of small contracts to the aerial survey company is much greater in proportion to the "direct" cost than it is when large contracts are involved. The result is that the cost to the client per square mile decreases as the area to be done increases. *Secondly*, the cost of a survey to the client depends upon the cost of getting the flying equipment to the job and of providing it with aerodromes or landing grounds on or near the job, if none exist already. These costs, obviously, are extremely variable and cannot be estimated without knowledge of local conditions. They may bear so heavily on some small isolated areas as to make aerial survey out of the question for them; on the other hand, in the case of a survey carried out in open country comparatively near the headquarters of an aerial survey company they may be very small. When the area to be surveyed is very large these costs, like the "overhead," may be spread so as to affect the cost per square mile to only a minor degree. *Thirdly*, the service required may range from vertical photography and the provision of a set of contact prints to the provision, in addition, of controlled mosaics and line-maps on various scales and of many different degrees of "control" or accuracy. The different kinds of service represented are such that no estimate whatever can be made until the fullest particulars are known. *Fourthly*, the direct cost of the photography depends not only on the climatic conditions ("waiting for skies" can be very expensive in a country like Great Britain) but on the relief of the country photographed and the degree of control, or absence of topographic displacement, required. *Fifthly*, the direct cost of the photography depends upon the scale at which it is done, varying roughly as the square of the scale expressed as a representative fraction. This relation is not strictly true, but it is near enough for a first approximation.

Considering only vertical photography (in which, it is believed, geologists are likely to be chiefly interested) *and ignoring the cost of getting the aeroplane to the job and the cost of furnishing aerodromes*, the cost to the client of a set of contact prints on a scale of 1:15,000 for a large area might be as low as 30s. to £2 per square mile under fairly good conditions, and with 60 per cent. overlap between successive pictures. For a controlled mosaic, the cost might be doubled or tripled, depending upon the amount of relief and the accuracy of matching required.

On the other hand, a controlled mosaic of a small area (say 50 square miles), under similar conditions, and on a scale of 1:5,000 might cost over £30 per square mile. These figures must be taken with the very greatest reserve; and a quotation, based upon a knowledge of local conditions and of exactly what has to be done, is the only safe basis for estimates.

The cost of making purely topographical maps, whether from vertical or combined vertical and oblique photography, cannot be discussed here. If large areas are concerned, the cost can be reduced to a low figure, but such mapping is of no *direct* concern to the geologist.

The cost of visual reconnaissance, likewise, depends much upon the size of the area to be done, the local conditions, and the necessity or otherwise of providing aerodromes. The estimation of the cost for a given job is, however, not

so difficult as the cost of estimating the cost of photography, since, for any area, there is likely to be some experience available of the cost of running (or hiring) a light aeroplane.

4. The Interpretation and Use of Aerial Photographs by the Geologist

Oblique Photographs

Oblique aerial photographs approximate somewhat to views that are obtained from the tops of high hills, and most people have no difficulty at all in reading them. Oblique photographs are used in mapping in fairly flat country (*e.g.*, parts of Canada and Northern Rhodesia) and such photographs may sometimes be available to geologists. They are useful to reveal the relative heights of hills and depths of valleys, and for general observation or study (43). They are said to be especially valuable in regions of flat-dipping sediments (56).

Where they can be used for mapping, obliques are more economical than verticals on account of the much larger area covered on each photograph, but for scientific work they have the disadvantage of very rapid diminution of scale toward the background and consequent difficulty of recognition of features of interest, except in the cases where such features produce very bold effects.

Vertical Photographs

It is found that many people, even experienced surveyors, have difficulty in reading vertical photographs for the first time except when standing on the ground which they depict; that lack of experience of aerial photographs and lack of knowledge of the ground depicted are barriers to full appreciation of what is shown, and that:—

"as some real understanding of a region is obtained, the detailed interpretation of further photographs of the same region becomes increasingly easy; when a new region is entered, the work of interpretation has in many respects to be begun afresh." (Bourne, 94.)

While the quotation is given apart from its context, the present author believes it to be generally true.

Holding the Photograph.—If a vertical photograph is held wrongly, objects which are convex to the observer may appear concave, and concave objects appear convex. On rotating the photograph, the apparent shapes of objects will change and they will begin to appear as they really are. Trees in a forest and shallow depressions such as pits or stream-meanders are examples. Numerous rules have been given (7, 52, 94) for the correct position, but none of them is entirely satisfactory. The illusion depends upon the direction in which shadows are cast and the habit of the human eye, which does not normally see shadows on the far side of objects. The only entirely safe rule appears to be: Hold the photograph with reference to yourself and to the light incident upon it in such a position that objects which you know to be convex appear convex and objects which you know to be concave appear concave.

Interpretation.—With the photograph correctly held, there will usually be no great difficulty in the correct recognition of most objects on the ground. With a little experience, roads, railways, tracks, hedges, fences, vegetation, buildings, dumps and excavations will be correctly identified. In spite of the topographical displacement which differentiates the photograph from a true map, a vertical photograph is very much like a map, except for (1) the shadows, which give a sense of relief, once their value in doing so is appreciated, and (2) the immense wealth of detail, unobtainable in a surveyor's map at whatever expense.

"The great amount of detail enables one to pick out the particular features in which interested, and in this respect pictures have a greater variety of possible uses than topographic maps. The latter show only such features as were considered important by the topographer

or by the organisation for which the map was made. The many small details of topography, vegetation and culture make the determination of location comparatively easy. . . . An observer may meander above a small gully and determine locations of geologic features as accurately as when traversing a ridge from which there is an extensive view. When using a topographic map, one generally finds it necessary to climb from a gulley to the adjacent ridge in order to determine a location accurately." (English, 56.)

Colour Values.—In vertical photographs some confusion may be caused to the novice by the colour values of natural objects as expressed by differences in tone on the photographs. These differences, from what is observed when viewing with the eyes on the ground, are due to (1) the use of a colour screen (filter) which absorbs much of the blue end of the spectrum, and (2) the difference in the incidence of reflected light on the ground and in the air.

Clear, still water reflects little light into a vertical lens and appears black. Muddy water disperses light and appears light grey (19). Browns and reds tend to photograph white or light grey, while greens and blues appear as various shades of grey or black (93). Wet soils may appear dark, while the same soil when dry may photograph in a very light tone.

Such differences are responsible for differences of opinion among authors as to the relative visibility of objects in visual reconnaissance from the air and in photographs respectively. Thus, Crawford and Keiller (127), dealing with the discovery of archæological remains in Wessex through the visual observation of the intenser green of young crops growing on the loose subsoil of old ditches, state:—

"It is usually imagined that the camera, when fixed in an aeroplane, records marks on the ground which are invisible to the eye of an observer. This is not so. The observer can see these marks more plainly than the camera, *for he sees them in colour.*"

The difference in colour is more apparent to the eye than to the camera, and may even, in some cases though not in all, be distinguishable from the ground.

On the other hand, numerous American authors (*e.g.*, 56, 52, 44) give instances in which slight colour differences in soils resulting from the disintegration of certain beds enabled these beds to be traced on photographs in spite of the fact that the colour differences could not be observed by the eye.

Such differences of opinion may, it is thought, be reconciled when it is remembered that the eye is receiving impressions throughout the visible spectrum, while the film in the aeroplane camera is especially red-sensitive and has the blue light removed. Thus differences in the blues and greens (*e.g.*, crops and trees) should be more appreciable to the eye than to the camera, while differences in the reds and browns should be more appreciable to the camera than to the eye. The subject of colour values has been somewhat stressed here on account of the importance of slight differences in colour to the interpretation of geology from the air.

Stereoscopic Examination of Photographs.—Some form of stereoscope is indispensable to the aerial geologist, since it is essential for him to see the country "in the solid" in order to evaluate the structure from the topography. The stereoscope also makes easy the recognition of other features which are not resolved in single photographs.

The geologist, as distinct from the surveyor or mapmaker, does not require the stereoscope as a precision instrument, and, other things being equal, the best stereoscope for him to use is the one which is the easiest to carry into the field or the one which is the easiest to use. Some people are able to get stereoscopic fusion between the common portions of two contact prints without the aid of a stereoscope. The author cannot, and he imagines that it must be a considerable strain on the eyes and not to be recommended. For field use, the stereoscopic spectacles made by Stanley, of 286, High Holborn, are good. They are mounted in frames like those of ordinary spectacles and they fold into a case of very moderate dimensions. The "lenses" consist of combination prisms-and-lenses which have the effect of increasing the optical separation between the eyes, and

so enabling the common portions of two prints to be studied stereoscopically when placed side by side. These spectacles cost 16s. a pair, or 12s. 6d. if taken in quantity. They are somewhat a strain on the eyes unless removed immediately a pair of prints ceases to be looked at.

Various forms of simple reflecting stereoscopes are on the market. One of the best, and the easiest to use, is an open-legged form made for the Aircraft Operating Co. Its disadvantage is that, though easily dismounted for packing, the pieces take up a good deal of room. A good folding form is made by Barr and Stroud, 15, Victoria Street, S.W.1. This stereoscope is very handy in the field, as it folds compactly into a carrying case about the size and weight of an old-fashioned half-plate camera. This stereoscope is provided with glass cover-plates which serve to hold the two photographs being examined in position; the glass plates are ruled with grids, one of which is movable, and which enable relative heights to be judged as in a topographical stereoscope.

In placing two contact prints for examination under the stereoscope, the following points should be kept in mind:—

(1) Only that area common to the two prints can be examined stereoscopically.

(2) Two prints from the same negative will give no stereoscopic effect, and the amount of apparent relief obtained from a pair of photographs will be proportional to the distance apart from which the two negatives were taken.

(3) The photographs must be arranged under the stereoscope in such a manner that the air-bases (or lines joining the principal points of the two photographs) are in line and are parallel with the eye-base of the observer. Fig. 4 illustrates how this is done. AB is a heavy guide-line on the drawing table, parallel with the edge of the table and hence with

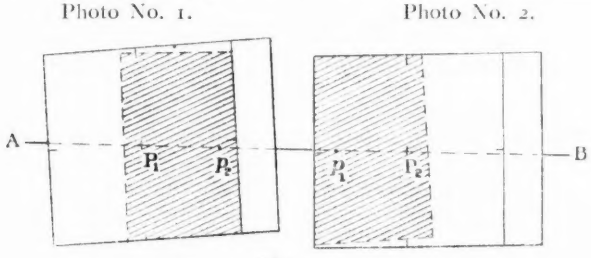

FIG. 4.

Two photographs arranged for stereoscopic examination.

the observer's eye-base. P_1 and P_2 are the principal points of the two photographs (marked by fine crosses on the photographs). p_1 is the principal point of photograph No. 1 located on photograph No. 2 by reference to detail, and p_2 is the principal point of photograph No. 2 located in the same manner on photograph No. 1. For satisfactory stereoscopic fusion P_1, p_2, P_2 and p_1 must all lie on the guide-line AB, which must also be parallel with the axis of the stereoscope. In the folding type of stereoscope, the centre-lines of the grid plates take the place of the guide-line AB.

In Fig. 4 the common overlap of the two photographs has been indicated by hatching. It will be noted that the air-base is not parallel with the edges of the photographs, owing to under-correction for "drift" of the aeroplane by the photographer—this is quite usual.

(4) The two prints must be situated in the same relative positions as when they were taken. Reference to the serial numbers and the direction of flight of the aeroplane will settle this point, if in doubt. If not so situated, a reverse stereoscopic effect is obtained in which the country looks as though it has been turned inside-out; with hilltops at the bottoms of valleys and streams running along ridges.

(5) Stereoscopic fusion is obtained by sliding prints about along AB until they snap into fusion; when fusion has been obtained, further slight adjustments may be made without losing it—into a position giving minimum eye strain.

If difficulty is found in getting fusion, markers may be placed on the same point of detail on the two photographs and the photographs moved along AB until the two markers appear to occupy the same position, with the eyes looking straight *through* the photographs. Getting fusion easily is largely a matter of personal idiosyncrasy and practice. Persons having only one good eye cannot use a stereoscope, and some people with eyes of unequal strength have great difficulty in getting fusion.

The stereoscopic view not only enables the country to be seen " in the solid," but it enables identification to be made of features that are so small or shallow as not to be appreciable in single photographs. For example, a tiny white mark on a single photograph may be resolved under the stereoscope into an outcrop of which the strike and possibly the direction of dip may be determined.

Minor topographic features, which may indicate faults or contacts, are seen much more clearly than in single photographs, and their alignments (in the case of faults) can be traced with great ease. Papers in the third section of the bibliography, and also that of Matthes (27), give many similar examples.

Systematic Examination of Sets of Photographs.—Everyone will develop his own system. A few hints may be given.

(1) Keep all photographs, except the pair actually under examination, in their proper serial order.

(2) Pay attention to the serial numbers of photographs and to the second-hand of the watch in the margins; apparent gaps or abnormal overlaps may thus be explained.

(3) The marginal data regarding lens and height flown give the scale, at any rate approximately.

(4) Get a general idea of a number of photographs and compare with what has been seen on the ground before attempting very detailed interpretation.

(5) *Don't make notes on the photographs.* All observations should be made on oversheets of tracing paper; or, better, thin matte-surfaced celluloid. Photographs that have been marked with either pen or pencil are ruined for any further investigation. Pencil dents the emulsion and renders stereoscopic fusion difficult; ink is almost impossible to wash away completely.

(6) A small reading glass assists examination of detail on single photographs, but, in general, the same detail will be seen much more clearly under the stereoscope without a glass.

Use of Vertical Photographs as Plane-table Sheets (adapted from paper by Matthes (27)).—Single prints enlarged to about twice linear dimensions make good plane-table sheets. Except in heavily-timbered country, traversing can be avoided and the position of the set-up fixed by reference to detail visible on the ground and in the photograph. Orientation, unless the line of sight passes through or near the principal point of the photograph, must be done by sighting on an

object at about the same level as the table. The speeding-up of the work of mapping is astonishing, since the location of most points can be made by direct reference to detail, however insignificant, which can be recognised both in the field and on the photo. In contouring, shots to the rodman can be approximately checked in the same way. In country of bold relief, the rodman can be dispensed with for contouring and differences of elevation obtained by vertical angle and scaled distances on the photograph (graphical correction being made in the field for the topographic displacement of points).

When using *mosaics* as plane-table sheets, certain difficulties arise from the non-matching of detail in countries of pronounced relief, but excellent results can be obtained in country of low or moderate relief. It is advisable in contour-sketching to make the contours fit the detail rather than to correct the latter for displacement. The resulting inaccuracies are for the most part minor.

Use of Photographs and Mosaics as Base-Maps.—The advantages of aerial mosaics as base-maps for doing geology, as compared with topographical maps, are briefly these:—

(1) The presence on the photograph of a great amount of detail *of a kind that the geologist needs and which is mostly absent from a topographical map* saves the geologist's time in the field, since a great part of his mapping is already done for him by the photograph (51, 56, 52).

(2) The possibility of self-location by reference to detail saves the time that normally has to be spent in fixing positions instrumentally and enables the geologist to concentrate on geology. It has been found in California that the use of photographs in the field may enable contoured maps to be dispensed with, and that the resulting saving in survey work may exceed the cost of the aerial survey (52). The contoured maps were replaced by stereoscopic study of prints and by a few cross-sections made by the geologist to determine the thickness of beds.

(3) The *quality* of the geologist's field work is likely to be improved, since in photographs or mosaics he has the opportunity of seeing things together which he can only observe separately on the ground (43, 26, 48).

(4) In 1930, three geologists of the Canadian Geological Survey:

> " undertook to use aerial photographs in the field instead of base maps. One of these parties was mapping on a scale of 1in. to 1 mile in mountainous country with a local relief of about 4,000ft. and found the photographs satisfactory. A second was working on the same scale in comparatively flat country and found the photographs even more satisfactory. The third, working on a scale of 1in. to 800ft. in a mining camp, was unable to use the photographs as a base. On the whole, this plan is promising and will permit geological and topographical work to be carried on simultaneously, and then produced in map form correspondingly quickly, in contrast to the ordinary practice whereby the topographical base maps must be undertaken at least one year ahead of geological field work."[7]

The author would again like to point out that plotting on photographs spoils them, and to suggest that, unless more than one set of photographs is available to the geologist (and they are expensive), all plotting should be done on transparent oversheets, preferably of celluloid.[8] This suggestion applies both to individual photographs and to mosaics.

5. The Aerial View: Visual Reconnaissance

So far only photography has been considered. Visual reconnaissance from aeroplanes is, however, extensively practised for obtaining information regarding natural resources. It has been employed on a large scale in Canada and Burma for the reconnaissance of forests, and, in Canada and Morocco, for geology.

[7] Director, Geological Survey of Canada, personal communication.
[8] Celluloid suitable for this purpose can be obtained from British Xylonite Co., Ltd., Hale End, E.4.

The Aerial View

Many writers have contributed toward our idea of the " aerial view," which is none other than the " bird's-eye view." Some writers consider it only in relation to visual reconnaissance from the air, while others think that it is contained also in aerial photographs.

Writing of the search for archæological remains in Wessex, Crawford and Keiller (127) say:

". . . the distant view is necessary to convert chaos to order. The reason for this necessity can best be explained by means of a comparison. If one looks through a magnifying glass at a half-tone illustration made through a coarse screen, it ceases to be seen as a picture and becomes a meaningless maze of blurred dots. If one holds it some distance off and looks at it with the naked eye, it becomes a picture again. The observer on the ground is like the user of the magnifying glass; the observer (or camera) in the air is like him who looks at the half-tone picture from a distance."

Writing of an aerial photograph of one of the ports on the Peruvian coast, Johnson (121) says:

" On the ground minor details obscure its simple essential features. From an aeroplane, *or better still, in an aerial photograph (for the camera catches and records much that the eye cannot grasp in the rapid flight of the plane)* one sees the whole scene spread out in a single unhindered panorama in which the broader features and relationships are lifted clear and unmistakably from the details that conceal them on the ground." (Italics mine.—D. G.)

Milner (25) says:

" Looking down . . . compels a new viewpoint of the earth's surface and a corresponding readjustment of physiographical, hence geological, ideas. Regarded from surface level, both elevation and depression, if markedly contrasted, tend to convey to the mind an exaggerated impression, largely because observations are more or less circumscribed. Aerial observation, on the other hand, because of its far greater scope and wider field, corrects such impressions. compels a truer perspective, and broadens the mind to think ' regionally '—that is, on a scale that is quite impossible merely from ground level."

Bourne (93) says:

" The view obtainable from the air by visual observation . . . differs from that supplied by photographs in that it is wider and is enhanced by colour. . . . From the air, colours are very distinct and of great significance in the interpretation of surface effects. Apart from colour differences, the observer obtains a general view of large tracts of country. . . . With good visibility, prominent features may be located to a distance of thirty or forty miles; if they are looked for, many details may be identified up to six or seven miles, but the tendency at a considerable height (8,000ft. or more) is to lose sight of detail and to see only the general surface effects. This last fact alone is of great practical importance, and therefore the significance of what has been termed ' THE AIR VIEW ' may be emphasised."

Similar quotations could be extended to several pages. It is evident that each one has a slightly different conception of what is gained by going into the air, and it is proposed briefly to summarise some of the important differences between *the different kinds of aerial view.*

Analysis of Aerial View.—The aerial view can be obtained from moderate heights (say, 1,000ft. to 4,000ft.) or from great heights (say, above 8,000ft.). In either event it can be obtained either with the eye or with the camera. At great heights the aerial view obtained *with the camera* may be stereoscopic or not, as we please.

Comparing the " aerial view," in general, with that obtained on the ground, it may be said that (1) from the air, large tracts of country are seen at one time (and with no detail in the foreground to obtrude itself), thus enabling generalisations to be made easily that could only be arrived at on the ground as the result of many successive observations—in other words, the view from the air gives a better perspective than that from the ground; and that (2) from the air access may be had to information not easily available on the ground, because either invisible to the ground observer or not appreciated by him at its true value. (*E.g.*, 25, 26, 44, 48, 52, 56, 58, 123, 127.)

Comparing photography with visual reconnaissance, it may be said that (1) photography sees only in tones of grey, but " visual " sees true colours, which may be of importance—but the photograph may be able to differentiate tones not separable by the eye; that (2) photography both sees *and records everything in great detail*, while the eye can only grasp a limited amount of detail, owing to the rapid flight of the plane, and can only *record* it as fast as the hand can sketch it or plot in on a map; that (3) the eye and brain, acting together, can " sum up " a view and record the boundaries of broadly-selected regions; and, finally, that (4) the eye, being swivelled, can at all times get a wider view than the camera can record in a single photograph.

Comparing the aerial view at moderate heights with that at great heights, it may be said that (1) the view from moderate heights corresponds with that from a high hill, while that at great heights corresponds with a map or relief model viewed from above; that (2) at great heights the eye no longer sees the country stereoscopically, even a highly accidented region appearing flat and featureless, while with the camera we may obtain stereoscopic vision from great heights over considerable areas at one time (the overlap of two 7-in. × 7-in. prints at 1 : 20,000 scale and 60 per cent. overlap is about three square miles); and that (3) at great heights the camera can still record permanently in great detail, while the eye sees only broad regions of colour and texture.

Visual Reconnaissance

It would appear from this tentative analysis that, to a great extent, visual reconnaissance and photography have different fields of application, which are complementary. Broadly, visual reconnaissance is applicable to the preliminary reconnaissance, when it is wished to get a wide view and make generalisations; while photography may be applicable at later stages, when it is wished to obtain greater detail and to make a permanent record of it.

Visual reconnaissance has been much used in Canada, both in prospecting operations for eliminating unpromising country (76, 83, 84, etc.) and for preliminary reconnaissance.

" What we formerly could do only from hilltops we can now do to better advantage from moving aeroplanes at greater altitudes. Such observation is particularly helpful in unexplored or little-explored parts of the pre-Cambrian shield, where travel is by way of streams and lakes, and where geological observation is hampered by dense forest growth. A preliminary observation flight in such territory usually reveals the water routes that can be traversed by canoe and also the rocky portions of the country that can be reached by traverse on foot. At altitudes of 3,000ft. or 4,000ft. it is not difficult for an observer to make a sketch of such features accurate enough to serve as a guide for later traverses on the ground."[9]

Such use of visual reconnaissance corresponds with that dealt with by Milner (25), whose paper is largely devoted to visual reconnaissance and to the recognition of geology from the interpretation of landscape. His conclusions regarding the conditions under which " visual " can be carried out are to the effect that there is a lower limit of height of about 1,000ft., below which there is a tendency to centralise detail (that is, below which the advantage of the aerial view is lost, D.G.) and an upper limit above which recognition of anything more than main features is impossible, and which he puts at 4,000ft. to 6,000ft.

In Scott and Robbins' report on the aerial reconnaissance of forests in Burma (130) a good deal of consideration is given to the conditions under which fairly detailed recording of vegetational differences in forests can be done by visual reconnaissance from the air. Their aeroplane speed was about 80 m.p.h. and observations were plotted on a map at 1in. = 1 mile. Their conclusions might be roughly summarised as follows:—

[9] Director, Geological Survey of Canada, personal communication.

(1) Flying height must be determined by the minimum cruising speed of the aeroplane, to allow the observer to plot observations without continual circling. At 10,000ft. it was found that this could be done; if flying lower they found that they were obliged to circle to give the observer time.

(2) Flying height, at a given speed, depends also upon the amount of detail to be mapped; this fixes a maximum height above which the detail which it is wished to map is indistinct.

(3) If there is a great amount of detail in a certain area it may be necessary to narrow the width of strip observed.

(4) Very little vertical observation was done (owing to slip-stream and exhaust interfering); most observation was confined to a flank behind the bottom plane. A strip 2-3 miles wide was taken, the near edge of which was about a mile from the plumb position of the aeroplane.

(5) Reconnaissance throughout was carried out on the basis that the prime duty of the observer was to recognise constantly on his map the topographical features he saw on the ground. If the observer got " lost " valuable flying time would have been expended in returning to some well-defined feature.

(6) There was no systematic check on the work, but it is thought that no observation was plotted more than about $\frac{1}{4}$ mile away from the correct position. (This, of course, would depend greatly upon the type of map furnished and upon the capability of the observer.)

(7) It was found necessary to colour-up the whole of each strip as it was observed, in order to avoid unobserved gaps.

The area of this survey was about 15,000 square miles and the rate at which it was carried out was about 230 square miles per hour, which included all flying other than transport flying. The conclusions reached do not necessarily apply numerically to geological work, but they may give food for thought and promote discussion.

Applicability of Visual Reconnaissance to Geological Work.—The following *tentative* conclusions are advanced as to the proper field of applicability of visual reconnaissance from the air to geological work:—

(1) Preliminary visual reconnaissance can be used in entirely unknown country for the purpose of getting a general impression of it, both topographically and geologically. Sketches made during this reconnaissance would provide the basis of communications for work on the ground, since " directions of drainage, conspicuous topographic features, or positions of other outstanding landmarks " (25) would be determined. It is likely that this preliminary reconnaissance would also " provide the basic elements of geological survey " (25) in the shape of trend-lines giving an idea of the general strike-direction of the region, and so enable the geologist the better to lay out his traverses on the ground. This paragraph corresponds with Canadian practice.

(2) Where prospecting operations are in question in entirely unknown country, but where there is some idea as to the " locus " of mineralisation (based upon experience of somewhat similar country, as in Canada), such preliminary reconnaissance, combined with frequent descents to the ground for control purposes, can be used for making a separation between " promising " and " unpromising " country for prospecting on the ground. This is Canadian practice.

(3) Similarly in a country of sandy desert, or of flat-lying younger rocks, visual reconnaissance could be used to locate the inliers of older rocks deemed favourable for the occurrence of mineralisation.

(4) In country that has been mapped topographically, *provided the geology is simple and provided the contacts are readily spotted from the air*, visual reconnaissance, in conjunction with close work on " control " areas on the ground, can quickly produce a generalised geological map. This is the type of work done by Reyniers in Morocco (26). It is also what is proposed, in effect, by Bourne (91), though his proposals relate to a country in which the geological contacts, etc., are not at all easily followed.

(5) In any kind of country, visual reconnaissance might be very useful for " spotting " some specific features which may be hard to find on the ground but which show up well from the air.

(6) In country that is being mapped photographically for the geologist, it is highly desirable that he should go into the air in order to bridge the gap between his ground work and his photographs.

General.—It may be well to point out at this stage that different individuals vary greatly in their natural aptitude for observing from the air. In every case the first few flights are confusing to the novice on account of the unusual motion of the machine, the cramped quarters, the noise, the wind and the rapidity with which the country passes by. When confidence has been gained, the man with a natural eye for country, *who knows what he wants to see*, will find little difficulty in keeping track of the map-position of the aeroplane and its course, and in selecting what he wants to observe while rejecting non-essentials from his perception. Other individuals will never gain the required facility.

Before closing this review of visual reconnaissance from the air, it is desirable to say something about the type of aeroplane suitable for it. From what has been said already, it is evident that a low cruising speed is necessary; to a certain extent this may be attained by flying against the wind.

What is even more necessary is a little comfort for the observer, since no man can concentrate upon observation unless he is observing in comfort. Open-cockpit biplanes (relics in design from the days of the war, when it was important to have a good view and field-of-fire toward the tail as a counter to the high-speed enemy fighter) are not suitable for civil reconnaissance purposes. The observer is full in the slipstream of the airscrew and is obliged to wear goggles and awkward stiff clothing; he usually has very poor opportunities for the adequate deployment of his maps, and his field of view is restricted just where he wants it most. On the other hand, the modern high-winged cabin monoplane gives an excellent field of view downwards and this view can be obtained without exposure to the slipstream; there is plenty of room for maps and they do not give more trouble than in a closed motor car. The net increase in the efficiency of the observer, through comfort, is undoubted and will not be questioned. It is not attained at any increase of cost, since machines of the Puss Moth type have shown their ability to go anywhere with an economy equal to that of an open aeroplane.

6. Geological Inferences from the Air

It is obvious that visual or photographic reconnaissance from the air can only make inferences of a geological nature by *sight*, and hence only from those features of the geology finding expression at the surface in some manner by which they can be seen at a distance.

In some circumstances the solid geology will be entirely masked from the air over extensive regions. Before going into the conditions favouring " aerial geology " those conditions under which it is entirely impossible will be discussed.

Blankets.—The following list of blankets, which entirely hide the solid geology from the air, may not be exhaustive:—

" Recent."—Alluvium, river terraces, raised beaches, alluvial deposits, drifted soils, etc.
" Glacial."—Pleistocene glacial drift, moraine material, etc.
" Sand."—Desert sand, sea-beach, coastal dunes, loess.
" Superficial."—Superficial calcareous tufa, superficial quartzite, laterite, " bog-iron," and lateritic residual soils not necessarily reflecting the composition of the underlying rock.
" Vegetation."—Vegetation reflecting extreme conditions of soil-moisture such as moss and peat, tropical rain-forest, marsh, etc.
" Man."—Towns and other agglomerations. The immediate neighbourhood of mines and prospects. Cultivation (in part).

This list needs little comment. Many of these blankets are equally blankets to the geologist who stays on the ground, unless he digs. Dense tropical forest, growing in a moist soil which itself may not reflect any more the composition of the underlying rock owing to its " maturity," is a most impermeable blanket to the aerial geologist and there does not appear to be much hope of practising " aerial geology " in tropical countries of heavy rainfall. The blanketing effect of towns and agglomerations is obvious. That of the surroundings of mines may not be so obvious; it is found that the numerous tracks and cut-lines in the bush around a mine, or prospect, are so confusing on photographs that little geology can hope to be read. The closely-spaced cut-lines in bush, made for some of the geophysical methods, are especially annoying and if both photography and geophysical work are to be done on a property it is highly desirable that the photography should be done *first* (apart from the fact that it may yield information valuable to the geophysicists). Cultivation is not necessarily a blanket, but may be so. Instances of geological information being obtained from the air through crops are known (52, 58).

While blanketed areas are unfavourable to the practice of " aerial geology," the aeroplane can be, and is being, used to determine the boundaries of such areas in geological mapping. In Canada use is being made of aerial photographs by the Geological Survey

" to distinguish on our maps rocky areas from areas of country so heavily covered with glacial drift as to render prospecting operations impracticable. The photographs are taken first, the rocky areas and other geological information on them defined, and transferred to the base maps that are to be used by the geologist. The geologist enters the field with this information in map form, and with sets of photographs in his hands. He is thereby enabled to direct his traverses more intelligently than would otherwise be possible, and with a saving of time and effort that may amount to as much as 50 per cent. His resultant map is, in addition, more precise than would be possible by ground methods."[10]

Only in some very heavily-forested areas is such delineation of the drift-boundaries impossible from the air.

Similar mapping of the boundaries of other kinds of blankets will suggest itself as possible; such boundaries are often very easily picked up on aerial photographs.

Positive Inferences

It will be convenient to consider positive geological inferences from the air under the following heads:—

(1) Major land-forms.
(2) Minor land-forms and rock outcrops (both colour and form).
(3) The colour of residual soils (considered empirically).
(4) Vegetation (considered empirically).
(5) Plant ecology.
(6) The aerial view.

[10] Director, Geological Survey of Canada, personal communication.

The first four of these heads are regularly utilised, when applicable, by the geologist who remains on the ground. It is, indeed, the " aerial view " in each case which renders the interpretation of them in terms of geology more effective from the air than on the ground, and were it not for the advantages conveyed by the " aerial view " there would be no point in trying to interpret geology from the air.

Major Land-Forms.—The study of land-forms in the field, with or without the aid of a good topographical map, has long been a well-recognised method of getting clues to the structure of a region. Aerial photographs bring to this study fresh help, in that they provide a topographical map with a wealth and correctness of minor detail that cannot be got in any other way, and one, moreover, which can be studied at leisure " in the solid " with the stereoscope, in blocks of several square miles at a time.

The use of the stereoscope is deemed necessary in the study of aerial photographs by the forestry man or the plant ecologist, who are dealing with merely two-dimensional surface effects; how much more useful must it be to the geologist who is engaged in solving a *three*-dimensional problem.

So far as detailed interpretation of major land-forms from the air is concerned, any good book on geomorphology will provide the necessary hints. The aerial view may enable the instant recognition of structures which weeks of traversing on the ground would reveal less distinctly and certainly.

There are three factors which may limit the extent to which major land-forms can be used for the determination of structure from the air. These are:—

(1) " Superimposed " drainage in its early stages.

(2) Pleistocene glaciation.

(3) Extreme complexity of structure.

" Superimposed " drainage may persist for a long time, but, except in its very early stages, there is usually some evidence of its modification by the structure of the rocks actually under erosion, in the incipient development of " strike " streams. Such development can be recognised from aerial photographs (in which large areas are accurately depicted) before ever it would be appreciated on the ground, even though a good topographical map be available. Pleistocene glaciation is a more difficult problem. Barrington Brown and Debenham state:[11]

" The predominance in cold temperate countries of the land forms due to the Pleistocene Ice Age, now being transformed by fluvial action, adds complexity to the subject which is too great for adequate treatment here. The interpretation of land forms due to this combined action of ice and water is exceedingly difficult, and is a matter of keen debate or of directly opposing views."

The author has little doubt that this is the explanation for the difficulty that has been found in interpreting geology from the air from land-forms in parts of the temperate zone. What requires explanation, however, is the great success of aerial geology in the great " shield " area of Canada, all of which has been recently under ice. It is suggested that the explanation may be the following: That in Canada the rocks involved are old rocks, all more or less metamorphosed and crystalline. The two effects of this are (*a*) that the erosion-forms produced by the ice do follow closely the banding of the rocks (seen by the fact that many of the waterways follow the strike), and (*b*) that the rocks are still fresh and hard under the drift cover. Where the drift cover is removed, actual rock is exposed. In Europe, on the contrary, many of the rocks are comparatively younger and softer, so that the erosion-forms produced by the ice do not follow closely the structure of the rocks, and where the drift is removed the rocks are commonly disintegrated to a subsoil. The author is not personally closely in touch with " glacial " geology and would welcome discussion on this point.

[11] " Structure and Surface," Barrington Brown and Debenham, p. 123.

The following *tentative* conclusions appear to be justified regarding the interpretation of geology from the air with reference to major land-forms:—

(1) The more mature the topography, the more likely it is to reflect the structure in the drainage and hill ranges in a manner recognisable from the air. This is especially the case if the drainage has been " superimposed " on the structure of the rocks now under erosion.

(2) In sedimentaries, those composed of rocks of very diverse resistances to erosion are more likely to develop characteristic forms than thick series of very even resistance.

(3) Those regions which have suffered Pleistocene glaciation are unlikely to have developed a drainage pattern, recognisable from the air, dependent upon the structure *unless* (*a*) the rocks affected are of such resistance that the ice-sheet itself brought out their structure, and (*b*) weathering since glacial times has produced no great depth of subsoil (*i.e.*, that clean rocks are exposed where the glacial-drift cover is removed).

Minor Land-Forms and Rock Outcrops.—While major land-forms are very helpful from the air in getting an idea of the megascopic structure of a region, minor forms and rock outcrops are frequently indicative of the details of dip and strike and of quite small breaks in the general structure. From the air their significance can be appreciated (chiefly from photographs) much more easily than on the ground. This comes from the possibility of recognising on photographs " alignments " of features which would never be recognised as such on the ground and which are too insignificant to appear even on the best maps.

Even where the topography is too youthful for the major forms to correspond with the rock structure, the minor forms and the rock outcrops, taken together and considered in the light of the aerial view, are frequently most illuminating.

The variety of geologic inferences possible under this head is very great in country which is at all favourable—and " favourable " includes much country which, to the inexperienced observer on the ground, would at the first glance appear unfavourable.

The following list of possible inferences is probably incomplete: Contacts between formations (24, 48, 52, 58, 83), details of bedding (25, 26, 27, 44, 45, 49, 52, 56), strike and dip (24, 25, 27, 43, 56, 58, 91), folds (25, 58), systems of joints (25, 49), scarps (25), mode of weathering (25, 27), relation of structure to minor drainage (43, 49, 56, 58), sinks in limestones (27), faults (24, 25, 27, 43, 44, 48, 52, 56, 58, 118), shear zones (83), quartz veins (83), intrusives (76, 82), the direction of foliation in gneissic granite, and the probable presence of silicification.

It is quite impossible to give detailed hints toward interpretation, because every country is so different in the way in which the geology expresses itself. The only hints that can be given are:—

(1) To know something of the country both on the ground *and from the air.*

(2) To have some idea of what the photographs ought to reveal in the particular country being studied, and to look for it, keeping the eyes and mind open to impressions.

It is in connection with the inferences under this heading that the stereoscope is of supreme importance, by its exaggeration of minor features in the relief of the country; scarcely less important is the " aerial view " which permits of " alignments " being spotted. The greater number of inferences under this heading will be made from the stereoscopic study of photographs.

The following *tentative* conclusions regarding the interpretation of geology from the air, with reference to minor land-forms and rock outcrops, are advanced:—

(1) The structure should contain at least some bands of rock which are considerably *more* or *less* easily eroded than the remainder and/or there should be present some kind of structural breaks.
(2) Inferences under this heading will be easier if the topography is not too mature.
(3) There should be at least some bands of rock that do not tend to form deep residual soils on weathering.

Soil Colour.—In many parts of the world, where the soil is " residual," that is, resulting from the disintegration *in place* of the underlying rock, the nature of the soil may be an indication of the nature of the underlying solid rock. Residual soil may be considerably modified by climate, the " maturity " of the soil and the type of vegetation growing on it (91), and geological investigations of large areas, if they are to be based at all upon soil characteristics, must be done upon the ecological lines briefly discussed separately.

However, there are many variations of soil colour (seen as variations of *tone* in photographs), which may be interpreted from the air along purely empirical lines. Such are the characteristic soils formed from basic intrusives and from pyritic mineralisation under some conditions of weathering and the banding of soil colour resulting from the weathering of stratified rocks of varying composition across the strike. These characteristics have been used in practice from the air, and reference may be made to the second, third and fourth sections of the bibliography.

The conditions under which soil colour alone may be used empirically from the air as a basis for geological inferences may be tentatively stated as follows:—

(1) The soil must not be so mature that extensive changes in it, in the direction of the formation of surface silica, calcareous tufa or laterite, obscure its relation to the underlying rock.
(2) The variation in colour must be distinct enough to be recognisable either by visual observation or in photographs.
(3) The soil must be truly residual, and " control " on the ground must verify this and determine the amount of creep or drifting of soil that has taken place.

Vegetation.—The influence of the underlying hard rocks upon the composition of residual soils formed from them can be seen from the air in many instances, not only in the soil colour but also in the nature of the vegetation which they support.

The influence of the underlying solid geology upon vegetation has been noted in parts of India and Burma[12], in South Africa (97), in Northern Rhodesia (91), and elsewhere. In can even be seen in Europe in places. The scientists specialising in plant ecology appear to have determined to their satisfaction that such influence has to do, very largely, with soil moisture conditions. For example, under given conditions of climate, aspect and slope, rock " A " will provide a residual soil in which the moisture conditions are such that a given species (or community of species) of plant will flourish, while rock " B " will not, owing to the difference in the moisture-retaining qualities of the soils from the two rocks. Under other conditions, and notably if there is heavier rainfall, the soils formed from both rocks may support somewhat similar communities of plant species. The differentiation of the underlying rocks by noting the differences in the soils formed from them and in the vegetation which they support (over limited areas in which there is no great variation in the conditions of climate or aspect, etc.) forms the basis of the ecological-geological mapping discussed under the next heading.

[12] Tansley and Chipp, " Aims and Methods in the Study of Vegetation," pp. 239, 243 and 296.

Here it is proposed to consider merely the empirical use of vegetation as a geological guide from the air, *without recourse to the ecologist*. This is simply an extension, with the aid of the aerial view, of ordinary geological methods. The aerial view enables the geologist, for example, to see vegetational banding much more clearly (either directly or in photographs) than it can ever be seen from the ground. Faults or contacts may be marked by lines of trees or bushes (corresponding to increased soil-moisture along their locus), or may display an abrupt change in vegetational habit on the two sides of the line of fault or contact. Such changes are seen with very great clearness from the air or on photographs. Banding of vegetation in light coloured (or possibly stunted) bands alternating with dark (or possibly well-grown) bands may likewise indicate stratification and is equally easily seen and mapped. Mineralisation may be responsible for vegetational changes at the outcrop, as in the extreme case of the Roan outcrop and the outcrops of the copper orebodies in the Haut Katanga. These are merely a few examples of the type of vegetational change that may be noted from the air as having geologic significance *and which do not need an ecologist for their interpretation*.

It should be noted that many of the changes in vegetation which are quite obvious to the layman on photographs, or from the air, might escape his notice on the ground, since they may be due to differences which *on the ground* would only be observed by a trained ecologist.

It must be further recognised that the intervention of man by cultivation, grazing, etc., may have considerably altered the character and distribution of vegetation and have produced differences which have no relation to soil or geology.

Thus the *empirical* use of vegetation in the interpretation of geology demands considerable caution and the exercise of common-sense.

Numerous references to the employment of vegetational differences in geological interpretation of photographs may be found in the papers in the second and third sections of the bibliography.

The conditions under which vegetational changes may be used *empirically* as a basis for geological inferences from the air cannot be laid down with great certainty, but it would seem that they would be most frequent and certain in rather dry countries or in those with well-marked wet and dry seasons, where the soil moisture is not great enough to ensure a uniform matte of vegetation.

Burrowing animals (rabbits, moles) or insects (ants, termites) might similarly be used from the air on occasion. In Rhodesia termitaries photograph very distinctly when there are a lot of them close together, and in some photographs the dense colonies are seen definitely to be banded. The reason for this has not been investigated, so far as the author is aware, but it is certainly ecological and probably connected with the availability of moisture at certain depths in certain soils, and so eventually linked with the nature of the soil and with that of the underlying rock.

Plant Ecology.—The relation between plant ecology and geology is well recognised. Mogg (97) and Bourne (91, 94) have dealt with this relation in connection with aerial survey.

Mogg's work related to the flora of the Vryburg and Pretoria districts in South Africa. These are both districts of semi-tropical continental climate, with well-marked wet and dry seasons and low rainfall (15in. and 26in. respectively). The Vryburg district varies from rolling country (Ventersdorp and Karroo) to peneplain (Dolomite). The Pretoria area is composed of more or less parallel ranges marking the quartzites of the Pretoria series separated by valleys corresponding to the outcrops of the shales. Details of the actual species of plants concerned would be out of place here, but Mogg's conclusions may be stated:—

" (1) Where a geological formation outcrops over a large area in a locality, it is liable to carry a flora so peculiar and characteristic as to be readily distinguishable, in its principal constituents, from the flora of an adjoining different rock in the same climate.

" (2) Where the underlying formation is masked over a large area by superficial deposits of at least 4ft. in depth (possibly deeper in the case of a soft, easily-weathered rock in a moist climate), the nature of the geology may have no influence on the surface vegetation. Where the rock is but shallowly covered and its derivatives contribute to the surface soil, a variable flora will result, which may or may not bear some relation to that on the pure outcrop of the formation.

" (3) That geological faulting, accompanied as it usually is by sharply-contrasted variations of rock, soil, water, accessibility, and such factors, but where the physiography has not been sensibly altered, may be discernible by the suddenly altered character of the vegetation on it.

" (4) That, therefore, ecological plant geography may be of material assistance to the geological surveyor and soil chemist; and as far as macroscopic geological surveys may be made from the air, the vegetation, properly used, may be of considerable value in charting well-defined geological formations."

Bourne's work (91) was over part of the area surveyed from the air in Northern Rhodesia in 1927. This is a plateau country of mature topography and continental tropical climate with well-marked wet and dry seasons and a rainfall of about 45in., mostly in the period November-March. The geology is well known in connection with descriptions of the " Copper Belt."[13] The soils are residual, of great depth and relatively mature. The country is covered with forest of a dry type, interspersed with open grassy, marshy glades (*dambo*), connected with the drainage. Bourne's study of the country was over a strip from N'Changa to Solwezi which had been photographed vertically and which he himself studied both from the air and on the ground. Omitting all detailed botanical matter, his conclusions were:—

(*a*) Within certain zones there is a definite correlation between the general vegetational types and the soil colour. In other zones there is no such correlation.

(*b*) Within certain zones the distribution of vegetational types or sub-types is by strips roughly parallel in direction. In other zones the distribution is by no means so regular.

(*c*) The native has concentrated his cultivation on certain yellow soils within a certain forest type (*Brachystegia-Isoberlinea*).

(*d*) That the distribution of the *dambo* varies in different zones. Some of them lie other than in the direction of the main drainage. From these facts he considers that it is reasonable to deduce

" that the distribution of the vegetational types and sub-types, considered in conjunction with soil colour and the form of the drainage system, indicates:—

" (*a*) Changes in geological formation.
" (*b*) The stratification of certain formations.
" (*c*) The outcrop of certain strata; and
" (*d*) The general direction of strike in stratified rocks."

Aerial survey comes in here by supplying, from photographs and from visual observation, the distinct banding of the forest, the direction of the *dambo* in relation one to another and, of course, photographs of any rock outcrops in relation both to the *dambo* and to the forest banding.

Bourne's conclusions have not, up to the present, received unqualified geological approval. An expedition was sent out in 1929 by the Colonial Office to test them, but no report has been published dealing with the expedition's activities. Other geological opinion varies from the damning to the distinctly encouraging.

The author personally has only a visiting acquaintance with the region in question, but from a study of the few aerial photographs that are available to him it appears that the banding in the forest (which can be seen without ecological

[13] For example: " The Geology of Northern Rhodesia," by J. Austin Bancroft and R. A. Pelletier. Guide to Excursion C.22 Int. Geolog. Congress, 1929. " The Copper Deposits of Northern Rhodesia," by Anton Gray and R. J. Parker. E. & M. J., 7, 14 and 21st September, 1929.

training) is quite distinct and is often parallel with the side drainage (the dambo) and also with such rock outcrops as exist. Not only is this the case, but the wide view obtained on aerial photographs may give clues to the major structure which would be exceedingly difficult to obtain on the ground without a lot of detailed traversing. These clues are obtained in the photographs through sudden changes, along well-defined lines, in the character of the dambo and of the forest, and in some instances these changes can be traced for many miles.

The thorough testing of the conclusions reached is urgent, since a geological approval of these conclusions, possibly with some modification, would open the way to the rapid geological and forest survey of large areas in Central Africa. Work on these lines is envisaged, with the geologist, the ecologist, the soil chemist, the forestry and agricultural experts all working as a team and obtaining complete data on a region for each of their specialities with far less effort than is now required to get incomplete data. The subject is too wide to be discussed here and reference is made to the excellent papers in the fifth section of the bibliography. The motto of the ecologists is that of Roger Bacon (1266) : " All the sciences are connected; they lend each other material aid as parts of one great whole, each doing its own work, not for itself alone, but for the other parts; none can attain its proper result separately since all are parts of one and the same wisdom."

Geological interpretation on ecological lines and with the assistance of aerial photography will, it is thought, be confined to countries satisfying the following conditions:—

(1) Plateau countries of mature topography, developing " residual " soils.

(2) The upper extreme of annual rainfall, above which inferences based on plant ecology will not be possible, is probably about 80in. in the tropics and considerably less in temperate climates.

The Aerial View.—Observations made under the five headings considered above cannot, in practice, be entirely separated from one another. What happens is that observations made under different headings support one another through the medium of the " aerial view." An excellent example of this is contained in Willis's " Aerial Observation of Earthquake Rifts " (118), in which an account is given of an aerial reconnaissance of the San Andreas Rift in California over a length of several hundred miles. The course of the rift was followed by successive observations of the alignments, within the zone of the rift, of feeder-valleys, lakes, ponds, ravines, landslide-scars, zones of lighter soil, a canal-like ditch, lines of springs, green marshes in alkali valleys, etc. None of these, alone, would have been enough to demonstrate the existence of an important regional fault, but the cumulative effect of their *continuity* is overwhelming. The rift in question is a fault which has moved at a number of different times, the last time being during the San Francisco earthquake of 1906. Almost any aerial photograph in a country of faulted rocks, and which is otherwise " favourable " for aerial geology, will furnish similar (though not so complete) examples, the line of a fault being traced here by one feature, there by another, and the two sets of observations being linked by the aerial view which (and *only* which) enables the connection (*i.e.*, the alignment) to be conveyed to the mind.

General.—Examples may here be given of some types of observations that do not fall readily into the classification dealt with above.

It is believed that about 1921 an oil company employed aeroplanes on a survey of the mouth of the Orinoco for the purpose of spotting oil-seeps by the destruction of the surrounding vegetation. No published paper describing this work has been found, and details would be welcome.

Old stream-meanders photograph excellently and may be readily distinguished even when so overgrown on the ground as to be difficult to find.

Wayland, in Uganda, is using aerial survey to determine the positions and courses of ancient river channels which are believed to have supplied the gravels (and gold) found in the modern streams.[14]

7. The Practice of Aerial Geology

Aerial geology is very new as a geological tool, and the published information about it is incomplete, scattered, rather inaccessible, and to some extent journalistic, as may be gathered from a perusal of the bibliography. In the various countries in which it has been practised, the aims and the methods have been very different.

No information has been found in the literature regarding practice in South America, Mexico, New Guinea, Borneo and the East Indies, which are referred to, by name only, in one paper (25). With regard to Northern Rhodesia, the only information about the geological end of the survey is contained in two articles in the *E. and M.J.* (119, 120), and they are not very informative. Bourne's suggestions toward interpretation of geology in Northern Rhodesia (91) have not been publicly discussed by geologists.

The United States.—The commercial use of aerial geological methods in the United States has been confined, so far as can be ascertained, to prospecting for oil in California and Texas. (Section 3 of bibliography.) Aerial survey is used extensively by the U.S.G.S. for the preparation of topographic base maps, but aerial photographs have been used only to a limited extent by that organisation for obtaining geological information.

The use of aerial methods by the oil companies has, naturally, been confined to certain areas of sedimentary rocks and to obtaining only such information as is required by the oil geologist, such as ascertaining the position, nature and extent of oil "structures," and tracing sedimentary horizons. Aerial geology seems to have been particularly successful in California in determining the existence of faults; there are several references to the location of previously unknown faults on photographs, in areas that had been closely geologised on the ground.

So far as can be judged, practice in the West tends toward (1) complete vertical photography, on a scale of between 1 : 10,000 and 1 : 18,000 of the area to be examined; (2) the use of contact prints, with the stereoscope, both in the office before field work is commenced and during the progress of field work; and (3) the preparation of a mosaic after the completion of the field work, if the latter indicates that the area is likely to be interesting enough to justify the cost of the mosaic.

There is considerable unanimity regarding the time saved in examinations, which is put as high as 50 to 80 per cent. in some cases. This saving arises (1) from the speed with which contact prints can be delivered (as against the preparation of a topographical map), and (2) from the time saved in the field by having much of the normal work of mapping appearing already on the photographs, by the possibility of self-location on the photographs and by the advantages conferred by the "aerial view." Further advantages claimed for aerial methods are (1) secrecy, when required, since much information about an area can be got without ever setting foot on the ground; (2) the improvement in the quality of the field work when working with photographs; and (3) the excellence of mosaics for illustrating office conferences.

Making due allowance for the character of some of the information, it is impossible to escape the conclusion that aerial geological methods in the American oil industry have been of considerable value to the industry.

Canada (Section 4 of bibliography).—The use of the aeroplane in Canadian geology and prospecting has to a very great extent been prompted by the nature

[14] *Mining Magazine*, March, 1932, p. 158.

of the country, with immense distances to be covered in country frequently difficult to traverse on foot. The present paper cannot deal at all with this " communications " aspect, highly interesting and important though it is.

Visual reconnaissance from aeroplanes for the purpose of finding the way about difficult country has already been treated. The further use of visual reconnaissance, which is most important in Canadian prospecting, is for the selection of " promising " and the rejection of " unpromising " country from the point of view of the prospector. This, of course, involves a knowledge of what " promising " country is, and of what it looks like from the air. One company is now employing engineers who are themselves pilots for this type of work. The following quotation from W. G. Jewitt's paper before the Canadian Institute of Mining and Metallurgy (83) gives the gist of this practice:—

" The light aeroplane, operated by engineer-pilot, finds a useful field in this work. With practice, based on a close study of a section of the ground, rocks may be recognised and classified from the air. Usually the major groupings of age may be recognised by topographic features when flying at the normal cruising altitude of 2,000ft. At lower altitudes, below 1,000ft., it is possible to make detailed classifications, checked by frequent landings at suitable points. In this way unlikely areas are eliminated and the field prepared for parties to be placed in more promising areas for more detailed work. By more intensive ground-work the field reconnaissance grades into prospecting."

The paper then goes on to detail the types of geological inferences that may be made in the country concerned.

Considerable use is being made of aerial photographs by the Geological Survey. Particulars of the use of photographs as base-maps have been given already, and of the delineation of drift-covered areas. The following additional information may be of interest:—

" The contacts between different formations can, in places, be recognised and transferred with complete precision from the photograph to the map. The photograph frequently shows faults and other geological structures much more clearly than these structures could be recognised on the ground. This appears to be due to the fact that an observer has anywhere from two square miles to ten square miles of country under his observation at one time in a photograph, whereas on the ground his observation is usually limited to a radius of a few hundred feet or yards. We have had a considerable number of cases in which geological structures are visible in photographs that could only be worked out by ground methods in a period of days, weeks, or even months, and even then not so satisfactorily."[15]

The aerial photographs yield them four kinds of information in the pre-Cambrian areas:—

(1) Boundaries of formations, after a few preliminary traverses on the ground to disclose the nature of the rocks.
(2) Faults, usually indicated by a change of relief when viewed stereoscopically.
(3) Long and sometimes complexly curved strike-lines in the crystalline sediments. These prove very useful in working out the structure, and
(4) Boundaries of the drift-covered areas, which are very precisely defined.[15]

Morocco.—Lt. Reyniers' paper (26) is the chief source of information about aerial geology in Morocco, though other officers have also practised it incidentally to regional survey work (124). Reyniers states that the geology of Morocco is infinitely more " readable " from the air than that of France, and that the lack of vegetation enables one to see the " anatomy " of the country. His method of work is to cover carefully a " control " area on the ground, then to see the same area from the air in order to accustom himself to the difference in aspects, forms and colours. Once he has " learnt " the control area from the air, he can proceed to extrapolate contacts from the air, plotting on a topographical map. He does not attempt to map the country systematically, square by square, but rather follows up easily-recognised contacts and tectonic lines for a start, as he considers this method gives the observer a better grip of the general structure

[15] Personal communications from the Director, Geological Survey of Canada.

and makes the final work of filling-in easier. When he gets into difficulties with aerial interpretation, through the advent of a new formation or through a change in facies of the old one, it is a sign to him to descend and work on a new " control " area. He considers that photography is necessary for the resolution of complex structures, but that where the structure is simple he can produce, from the air, a better-finished map than workers on the ground (apparently in making geological maps in Morocco a good deal of sketching from a distance, from horse or automobile, is practised).

The above is a condensed and rather free rendering of Reyniers' paper, which is well worth reading in the original. He gives a number of instructive examples and a long list of districts in which he has worked.

8. Future Possibilities of Aerial Geology

Aerial geology may be said to have " arrived " for the following types of work and in the localities named:—

(1) Prospecting for oil—Western U.S.A.
(2) Route-finding and elimination of unpromising areas by visual reconnaissance—Canada.
(3) Geological mapping—Canada.
(4) Reconnaissance geological mapping by visual reconnaissance in country where the geology is not too complex—Morocco.
(5) Mapping ancient drainage systems—Uganda.

The extension of the practice of aerial geology to similar kinds of work in other countries is probably only a question of time, of a change in the business situation permitting a resumption of prospecting and of publicity for results achieved.

Aerial geology has been attempted, but has unfortunately not yet " arrived," for reconnaissance geological mapping (in conjunction with prospecting) in plateau countries of deep residual soils, where the co-operation of the ecologist will be necessary to achieve results. The author is convinced that this is a fit subject for research by some strong organisation able to bear the considerable cost and willing to have patience if the desired criteria are not established in a few weeks. The lines for such research have been indicated by the ecologists, but may need some modification at the geological end.

Apart from its use in Canadian prospecting, aerial geology does not yet seem to have interested the mining industry.[16] The author, as a mining man rather than as a geologist, has been interested in the possibilities of aerial geological methods for several years and has formed the opinion that such methods could, in certain circumstances, be of definite aid in the close search for mineralisation. The idea involved is the same as that involved in the selection of " promising " areas in Canada, but with the addition of the desire to locate " especially promising " areas within the " promising " ones.

The modern search for mineralisation, whether called "scientific prospecting" or " commercial geology," is generally an attempt to follow up, as quickly and certainly as possible, some known or suspected " locus " of mineralisation. When the " locus " has been traced, intensive methods (geophysics, drilling or making holes in the ground) have to be employed.

It is in the work of tracing the locus of mineralisation along the surface that aerial geology should be tried by the mining industry—as a speeder-up of the ground geologists' work, in much the same way that it has been employed in California in oil-finding. It is quite unnecessary to go into minute detail here; indeed, impossible, since the forms taken at the surface by the various

[16] With the exceptions previously noted

" pointers " toward mineralisation vary so much from district to district. It may be said, however, that many of them can be recognised (and grouped together with the aid of the " aerial view ") very much more easily from the air than on the ground, in country that is at all favourable to geological interpretation from the air. (Reference may here be made to the author's articles dealing with two South African examples (29).) This is a field for aerial photography rather than for visual reconnaissance, and for close co-operation between the aerial and the ground work.

What is being suggested is nothing drastically different from the present practice of the commercial geologist, but he is merely being offered a new tool with which to sharpen his perception. This tool cannot be used in all mining fields, but there are many in which its use deserves to be developed.

9. Acknowledgments

As far as possible detailed bibliographical or other acknowledgments have been made in the course of the paper. Where they have not been made I can only express here my general indebtedness to those whose ideas have been unconsciously absorbed.

I am particularly indebted to Mr. W. H. Collins, Director of the Geological Survey of Canada, for permission to use extracts from personal letters which appear in the paper.

I wish to thank Mr. R. Gilman Brown and Mr. R. C. Kemp for severally encouraging the writing of this paper and for valuable suggestions. I also wish to thank Mr. Ray Bourne and Mr. Brian Russell for reading and criticising portions of the manuscript.

Some bibliographical references were kindly supplied by the Director of the United States Geological Survey, and some others covering Californian practice by Mr. Willard W. Cutler, Jnr.

I should like to express my thanks to the following Societies and Institutions for library hospitality and for help rendered in collecting material: Royal Geographical Society, Geological Society, Royal Aeronautical Society, Institution of Petroleum Technologists, Institution of Mining and Metallurgy, and Imperial Institute.

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76. Solving Aerial Prospecting Problems in Northern Canada. By Earl Hanson. *E. & M. J.*, 12th October, 1929, pp. 574-7.
A very interesting paper, dealing with aerial transport and the organisation of prospecting parties.

77. Aerial Surveying in Canada. (Anon.) *The Engineer*, 18th October, 1929, pp. 404-5.
Deals especially with the system by which all aerial photographs taken by the Canadian Air Force are filed and indexed for the use of the public. Original source of information unknown.

78. Aerial Exploration. By Staff of Northern Aerial Minerals Exploration Ltd. Introduction by J. E. Hammell. *Trans. Can. Inst. Min. and Met.*, vol. 32, 1929.
Important paper, dealing with the organisation of the reconnaissance of large areas, using aeroplanes for transport and visual reconnaissance.

79. Aerial Surveys in Canada. By A. M. Narraway. *Proc. Empire Forestry Conference*, Australia, 1928.

80. The Use of the Aeroplane in Mineral Development. By J. A. Wilson. *Proc. 3rd Empire Mining and Met. Congress*, part IV, pp. 119-39.
Deals chiefly with transport.

81. Yearly Reports on Civil Aviation, Canada. Dominion of Canada, Department of National Defence.

82. Preliminary Report on the Aerial Mineral Exploration of Canada. By G. H. Blanchet. Dept. of the Interior, Ottawa, 1930, 32 pp. Illustrations and maps.
Summary dealing with 1928-29. Mostly transport aspect.

83. Aerial Exploration. By W. G. Jewitt. *Bull. Can. Inst. Min. and Met.*, No. 288, April, 1931, pp. 456-65.
An excellent account of the organisation of Consolidated Mining and Smelting. Methods of reconnaissance, prospecting and supply are outlined.

84. Mine Development by Aeroplane. By Newton Wakefield. *E. & M. J.*, May, 1932, pp. 264-5.
Deals with the general usefulness of aeroplanes to isolated mines and with prospecting methods in Canada.

SECTION V. PAPERS RELATING TO REGIONAL SURVEY IN RELATION TO AERIAL SURVEY AND TO THE INTERPRETATION OF AERIAL PHOTOGRAPHS ALONG ECOLOGICAL LINES.

91. Aerial Survey in Relation to the Economic Development of New Countries (with special reference to an investigation carried out in Northern Rhodesia). By Ray Bourne, M.A. *Oxford Forestry Memoirs*, No. 9, 1928. Clarendon Press, Oxford.
Deals with the interpretation of geology, on ecological lines, from aerial photographs taken on the N'Changa-Solwezi road, Northern Rhodesia, during the R.C.B.C. aerial survey.

92. Air Survey within the Empire. By Ray Bourne, M.A. *The Air Annual of the British Empire*, vol. 2, 1930.
Indicates the part that could be played by aerial survey in comprehensive surveys of the undeveloped countries of the British Empire.

93. Air Survey in Relation to Soil Survey. By Ray Bourne, M.A. *Imperial Bureau of Soil Science, Technical Communication*, No. 19.
An interesting paper for geologists. Contains a complete bibliography of aerial survey in relation to soil survey.

94. Regional Survey and its relation to stocktaking of the Agricultural and Forest Resources of the British Empire. By Ray Bourne, M.A. *Oxford Forestry Memoirs*, No. 13. Clarendon Press, Oxford, 1931. Illustrated with aerial photographs and strip-mosaics, with accompanying geological and vegetational maps of country in the English Midlands.
Very highly technical; the first 66 pages should be read by the geologist. The reproductions of aerial photographs are excellent.

95. An Economic Aspect of Regional Survey. By C. R. Robbins. *Jnl. of Ecology*, vol. 19, No. 1, 1931. Reprinted as pamphlet by Cambridge University Press, 1931, 33 pp.
Covers much the same ground as No. 94 from a different aspect. Of considerable interest to the geologist.

96. Value of Aerial Photography in Relation to Soil Surveys and Classification. By J. A. Prescott and J. K. Taylor. *Jnl. of Council for Scientific and Industrial Research (Australia)*, November, 1930. Illustrated.
Relation between soil and vegetation in Renmark irrigation project.

97. The Flora of Vryburg District in relation to Geology *and* A Preliminary Account of the Flora of Pretoria in relation to Geology. By A. O. D. Mogg. *Compete Rendu*, 15th Int. Geological Congress, South Africa, 1930, vol. 2, sec. VII, pp. 638, *et seq.*
"So far as megascopic geological surveys may be made from the air, the vegetation, properly used, may be of considerable value in charting well-defined geological formations."

SECTION VI. MISCELLANEOUS.

111. Editorials in *E. & M. J.*, dated 14th February, 13th March and 17th April, 1920.
Deal with possibilities of aerial mapping and transport in relation to Mining. Geology is barely mentioned.

112. Airplanes for Geologic Explorations in Inaccessible Regions. By B. Coleman Renik. *Bull. Am. Soc. Pet. Geologists*, 1925, pp. 947-57. Illustrated with pictures of aeroplanes.
Largely devoted to the aeroplane as a means of transport and for topographic mapping. Geological inferences possible in the Western U.S.A. are mentioned.

113. Spotting Mineral Deposits by Airplane. By A. J. Moore. *E. & M. J.*, vol. 128, 23rd November, 1929, pp. 812-3. Illustrated with two oblique photographs.
Short record of flights in Nevada.

114. Aerial Eyes on our Minerals. By C. Moran. Burroughs Clearing House, February, 1930.
Unobtainable.

115. Air Survey for Hoover Dam. By A. B. Beadle. *Aero Digest*, July, 1931.

116. The Physiography of the Western Macdonnell Ranges, Central Australia. C. T. Madigan. *Geographical Jnl.*, vol. 78, 1931, pp. 417-433. Illustrated with aerial photographs showing geology.

117. An Aerial Reconnaissance into the South-East Portion of Central Australia. By C. T. Madigan. R. G. S. Australia, P. South Australian Branch, vol. 30, 1930, pp. 83-108.
These two papers deal with route-surveys mostly over sandy desert country and over the Macdonnell ranges. Geological trend could be plotted from the air.

118. Aerial Observation of Earthquake Rifts. By B. Willis. *Bull. Seismol. Soc. America*, vol. 11, No. 2, June, 1921, pp. 136-139. Republished in *Science*, New Series, vol. 54, 23rd September, 1921, pp. 266-68.
An account of the visual reconnaissance from the air of the San Andreas Rift, California.

119. Prospecting for Copper by Airplanes. By George L. Walker. *E. & M. J.*, vol. 122, 9th October, 1926, pp. 576-8.
Deals with project for survey by R.C.B.C.

120. Surveying from the Air in Central Africa. By George L. Walker. *E. & M. J.*, 12th January, 1929, pp. 49-52. Illustrated.
Deals with the aerial survey of the R.C.B.C. concession.

121. Peru from the Air. By Lt. George R. Johnson. *American Geographical Soc., Special Publication*, No. 12, 1930.
Contains a large number of oblique photographs taken in Peru, illustrating well the nature of the "aerial view." Some of the photographs indicate the probability of interesting geology being observable in verticals of the same areas.

122. Aerial Mapping in Mexico. By K. Sagendorph. *Pop. Aviation*, April 1929, pp. 20-22.
Unobtainable. Subject matter unknown.

123. Reconnaissance Aérienne au Ledja et au Safa. By R. P. A. Poidebard. Extrait de la Revue "Syria," 1928. *Also* "La Géographie," *Bull. Soc. Géogr.*, vol. 52, 1929, pp. 1-17. Illustrated with aerial photographs.
An account of an attempt to verify the law of alignment of volcanic craters (in Syria) along fault-zones, by means of the "aerial view."

124. Les Pays Inaccessibles du Haut Draa (Un essai d'exploration aérienne en collaboration avec les Services des Affaires Indigènes du Maroc). By Capitaine Pennis et Lt. Spillmann. *Revue de Géographie Marocaine*, vol. 8, Nos. 1 and 2, 1929, 61 pp. Profusely illustrated with aerial strip-mosaics.
An account of a regional survey in Morocco. Some geological inferences were made. The reproductions of photographs are of poor quality.

125. Alaska's Flying Gold Hunters. By J. M. Nelson. *Pop. Science*, September, 1929, pp. 52-3.

126. Air Photography for Archæologists. By O. G. S. Crawford. *Ordnance Survey Professional Papers, N.S.*, No. 12, 1929. Illustrated.

127. Wessex from the Air. By O. G. S. Crawford and Alexander Keiller. Oxford: Clarendon Press, 1928.
Contains a remarkable series of aerial photographs of archæological discoveries in Wessex. Bibliography of aerial archæology.

128. Prospecting by 'Plane. (Anon.) *Queensland Govt. Mining Jnl.*, 15th July, 1932, p. 197.

An account of proposed work in Northern Australia. Forecast of the possibilities of aerial prospecting in the parts of Australia difficult of access on foot.

129. L'emploi de la Photographie Aérienne dans les Colonies et les Prospections Minières Coloniales. A. Carlier. *Revue de l'Industrie Minérale*, No. 273, 1st May, 1932, pp. 179-182.

A purely journalistic write-up of aerial survey, containing little of value to the geologist.

130. Report on Aerial Reconnaissance, Stockmapping and Photography of the Forests of the Tavoy and Mergui Districts. By C. W. Scott and C. R. Robbins. Rangoon, 1926.

An account of an important reconnaissance survey, with valuable remarks on methods of flying and visual observation in this type of work.

131. Aero Photo Survey and Mapping of the Forests of the Irrawaddy Delta. By R. C. Kemp, Major C. G. Lewis, C. W. Scott and C. R. Robbins. Maymyo, Burma, 1925.

A good technical account of an early photographic survey.

Discussion

Professor P. G. H. Boswell: His own experience had been confined to what he might call casual aerial photography. He had either seized opportunities for photographing geological features when travelling by air, or had taken a flight for the purpose when it had seemed to him that geological phenomena could better be recorded from a height than from *terra firma*. He could claim, however, to have taken a lively interest in the addition of this new weapon to the armoury geologic from the time when he realised its possibilities during the war. As a result of his limited experience, he welcomed Mr. Gill's valuable conspectus of what had been and what might be achieved.

Most of what he had to say was concerned with oblique photography, whereas it was clear from the author's exhibits that he was emphasising much more the vertical systematic aerial survey. But much information could be obtained through the interpretation of the oblique survey pictures. Oblique photographs should be taken by a geologist, or, if not, a geologist should be able to go up with the two sets of pictures, oblique and vertical, in his hands, so as to interpret them.

One very valuable use of aerial photography for geological purposes had been but lightly touched upon by the author, probably because its applications to those aspects of economic geology that interested the Institution would appear to be only indirect. He referred to the photography of inaccessible features, or of those only accessible with difficulty. The possibilities of aerial photography were first brought home to him by an example of this type.

In 1918, while at Harvard, he was shown a recently-constructed model of the volcanic crater of Kilauea in the Sandwich Islands. This crater, about two miles in length, and nearly a mile in breadth, was occupied in part by a great lake of molten lava. There were obvious difficulties inseparable from surveying such a lake by sailing a boat on it—rather a Dantesque adventure! He was informed that the details of the geography and geology necessary for the construction of the model were obtained from aerial photographs. Failing a view of Kilauea from the air, he showed a lantern slide of the great crater of Popocatepetl in Mexico, 18,000ft. in height, as an example of what could be done.

As a second example, he referred to the geological mapping of a region such as the Alps, where the geologist was often called upon to lay down lines on mountain faces difficult of access even to highly skilled climbers. The geologist could not follow his lines and place his points of contact with exactitude, as he

was wont to do in more subdued country. Withal, Alpine mountain structures were exceedingly complicated. Aerial photography had come to the geologist's aid. Often the rock types and rock structures were discernible on the photographs; in other cases the geologist repeated the flight, photographs in hand, and drew on superposed tracing paper a key to the structure. Some ten years ago, in that very room Professor L. Collet, of Geneva, used such photographs to illustrate his account of Alpine structures.

As a third example, he chose the systematic annual survey of Swiss glaciers, carried out by Professor P. Mercanton and his colleagues. It was not necessary to emphasise that in Switzerland, so dependent on its water supplies for power schemes, the amount of snowfall and the growth and retreat of the glaciers, which stored and liberated water, were watched with great anxiety. Not all parts of snowfields and glaciers could be traversed with safety; at the best, progress was slow. But air photographs could be utilised as pictures of a whole drainage system and might be compared from year to year. He showed two of these on the screen.

The success which had attended Mr. Crawford's efforts to photograph ancient human sites in Wessex, not visible at ground level, had inspired geologists to schedule certain land forms for aerial photography in Britain. The British Association was at the moment trying to arrange for the photography of the glacial overflow channel area of Cleveland, Yorkshire, in the belief that features not at present recognised would be revealed. The Harlech Dome and neighbouring country in North Wales had also been recommended for photography in the hope that structure lines would be emphasised in the aerial pictures. A week or two ago, he was informed at Leicester that aerial views taken of parts of the Midlands had shown up rock features in a surprisingly gratifying manner.

Turning to Mr. Gill's paper, and with an eye to the economic bearings of mineral wealth, he could strongly support his claim that aerial surveying was of great economic value for reconnaissance work in unsurveyed country, especially where it was heavily clothed with timber, or dotted with lakes, or ramified (like a delta) with braided streams. Apart from geology, the position of clearings, possible sites for camps, and feasible routes could be determined. The Director of the Geological Survey of Canada, Dr. W. H. Collins, had borne ample testimony to its value in this respect. He recalled that the exploration of the oil potentialities of north-western Canada was carried out in this way just after the War. Further, the existence of rock outcrops, the alignment of rock ridges and the form of major rock structures could frequently be detected with ease. He illustrated these by a series of photographs of an anticline and trend lines in the pre-Cambrian of the MacDonnell Ranges of South Australia, by Dr. Madigan; some recent fault-scarps in California; and the Zambesi rapids, Victoria Falls and gorge.

It was by means of the aeroplane photographs that Dr. Madigan was able to establish geological relationships in South Australia which had not been definitely established before. In the Californian photographs, he pointed out the indications of the San Andreas fault that ran through San Francisco, where, it would be remembered, a disastrous earthquake occurred some years ago. From the ground one could not see the fault so well brought out as in the aerial photograph. The other area from which he showed photographs was Rhodesia, and the example chosen was the Zambesi River, Victoria Falls and gorge. The mode of origin of the gorge of the Zambesi was for many years a matter of controversy, for it was remarkable that the River Zambesi should be confined to a narrow zigzag gorge in the area below the falls. Had aerial photography been available in the days of that controversy, he thought the explanation would have been reached much more quickly. Mr. Gill was of the opinion that he could

see on the map the signs of faulting or of shattering. When in that area, it occurred to the speaker at once from ground level, that here was a case where a good deal of light on the structure could be obtained by flying, so, with a student of his who was present that evening, he went up, and he showed the meeting photographs taken from the air—including oblique views of the region. These aerial photographs, he thought, brought out clearly the reason for that particular course of the Zambesi River.

At the moment the greatest value of aerial surveying for economic purposes would appear to lie in reconnaissance work in " new " countries, of which Canada, South Australia, and Rhodesia were examples. The importance there of obtaining what was literally a bird's-eye view of large areas was inestimable. It might be expected to reduce considerably the costs of exploration, and to influence notably the course of ordinary geological surveying. The broad structural features which were due to the different textures of rocks were likely to be brought out, no matter what the geological age of those rocks might be. Structures such as faults, however, were best revealed when they were of comparatively recent date. " New " topography (speaking geologically) was much more strikingly revealed in aerial photographs than mature earth forms, as a flight over the Alps, the Jura mountains, and the Paris basin well emphasised. Great care should be exercised not to pin too much faith to contacts between rock formations. Knowing the difficulty of placing these accurately when the rocks could be hammered, the geologist would not care to trust aerial views too far. On the other hand, he was in entire agreement with the author regarding the possibilities of delineating boundaries of glacial drifts in certain areas, ancient streams and river terraces, all of which might have important economic bearings. Ecology as revealed from the air had also a great value.

In conclusion, he wished to say that Mr. Gill had established his case for the use of aerial photography in economic geological work by so many excellent examples, that he hoped he would not try to claim too much for the method in the matter of obtaining and relying on small details of earth features.

Mr. N. E. Odell (who was introduced by the President as having recently taken part in an expedition to the coast of Labrador): He felt singularly incompetent to contribute anything of value to the discussion because he had had the opportunity of utilising " aerial geology " relatively little. He had used it to some extent in Canada, but on the economic side he had scarcely utilised it at all. Consequently the remarks that he would make in the discussion were perhaps a little outside the scope of the paper. What he proposed to do, was to show a few slides which were reproduced from aerial photographs that were made in the course of the Grenfell-Forbes Northern Labrador survey expedition last year, to which he himself was geologist. It was realised by the members of that expedition that, if any contribution could be made within the short time available in the summer season for survey work in the extreme north of that country, aerial methods would have to be adopted.

The matter was gone into particularly by Professor Alexander Forbes, of Harvard University, at the American Geographical Society, because in that society an officer—Mr. O. M. Miller, incidentally an Englishman—had recently developed a method of oblique aerial photography, which he called planetabling from the air. His paper was mentioned by the author in the bibliography. By this method, which was to be tested out during the survey of Northern Labrador, it was intended to cover a very large area with a very low expenditure of flying time. The actual construction of the contoured map from the abundant photographic material was still proceeding, and it was hoped that it would be completed within the next few months on a scale of 1 : 50,000. He thought, however, that it might be instructive to show a few examples of the photographs taken

during the course of that survey, because these pictures did give an immense amount of information of a useful character about the physiography of the country as well as the glacial geology.

The speaker first showed a map of Northern Labrador, and pointed out the area concerned, which was the extreme northern part of the peninsula. It was a very small portion of the country, which had been scarcely visited in the past, and one which was notable for the high mountains that voyagers up and down the coast had frequently reported and had declared to be the highest mountains in the eastern part of North America. The survey, however, showed that this is not the case, since no summits exceed 5,000ft. in all probability. Actually the survey that was made had been extended during this last summer right down to the neighbourhood of Nain, so that a very considerable portion of Northern Labrador would have been covered and surveyed topographically when these results were fully worked up.

The actual base of operations that was selected in 1931 was a little cove in Seven Islands Bay at Lat. 59° 22′. In this locality a ground control by triangulation was established on a level neck of land, and the local network embraced various peaks and other points. Another network was later established in the extreme north of the region, and the two tied in together, so that there were two triangulation nets about 50 miles apart. These had served as a complete ground control for the oblique method of survey adopted for the region.

He showed a large scale map and indicated a few of the problems with which the expedition was faced at the outset. For example, one of the things that was in extreme doubt in Labrador was the question of the coast line. It was also thought that the mountains of the north were probably a single range, extending roughly north and south in the neighbourhood of the coast. Actually it was found that the Torngat mountains alone (apart from other ranges to the southward) were of threefold character—a northern range, a central range, and coastal mountains embodying several groups. The outline of the west coast was very vague, and as for the multitude of islands and inlets which existed up and down the coast, even major openings were only vaguely represented on the maps. By a comparison of maps he indicated some interesting discrepancies.

The mother ship of the expedition was a schooner of about 70 tons burden, which served as a very excellent ship for the main party, consisting of 16 members, apart from the aerial section of four. The aerial equipment consisted of two planes, a Fairchild monoplane and an auxiliary Waco biplane, and from the Fairchild machine all the photography was done. It was equipped with a Fairchild aerial camera, giving photographs of about 7 × 9in. Another slide showed the actual flying work accomplished, with the southern and northern triangulation nets. The flying was carried out at altitudes of from 4,000 to 9,000ft. A series of photographs off shore, both on the east coast and the west coast, were obtained, and a number of flights were taken through the interior at varying altitudes to bring out the relief. In all, some 500 photographs were taken. Of course, the actual flying conditions in that country were generally bad, but on one exceptional day 330 photographs were taken during seven hours of flight. The man with the camera was a very much exhausted individual when he got in at the end of that day, seeing that the aerial camera weighed about 60lb. he believed, and had to be manipulated entirely by hand.

At the base a dark-room was improvised, where the films were developed as soon as the flights were terminated. This dark-room was a little lean-to fitted with running water and heating apparatus, not far away from the anchorage of the schooner. The flights which were taken off shore showed country of the unprepossessing character which appeared in the photographs he exhibited. This, the northern part of the Torngat region, gave a coast line which was definitely

that of a submergence, although the evidence of raised beaches indicated that it had been recently emerging. That also was the character of the country on the west coast, showing a " drowned " topography, a most inhospitable looking country, even more so on the west than on the east, which was the particular concern of the expedition.

The low altitude flights showed some fine mountain groups, and there was indicated in the coastal peaks and ridges a fairly advanced stage in the glacial cycle of erosion, although the mountains of the interior approximated more to a stage of early maturity. Certain of the peaks were visited by members of the expedition actually on foot, and one was not able to judge very much of the character or indeed of the structure of the solid geology of this region from the aerial photographs. What he found was that from the collection of photographs he now possessed very valuable deductions could be made with regard to the physiography and the glacial geology.

Another photograph exhibited showed a part of the interior ranges where, before the expedition went out, a question had arisen as to the actual character of the valleys, and as to where they led. It was discovered by the expedition that what had been thought to be closed valleys and lakes lying in the recesses of the Torngat mountains were really great " through valleys " that led through to the western side of the watershed. He indicated a great inland fjord which was a definite line of drainage for the Labrador ice sheet when it was existing. In the interior of Labrador during the Pleistocene period there must have been, at all stages of its existence, an outlet to the Atlantic through these valleys, and at certain stages it must have overtopped the mountains. He had discovered on some of the mountains definite evidence of glaciation. Several of the photographs, including one of the peak known as Mount Blow-Me-Down, brought out evidences of pre-glacial features. He referred also to the Mount Razorback range, which was of a different character from that of the ruling gneisses and other metamorphic rocks of the region. During a flight he saw that there was something distinct about this range, and later, on climbing it, he found that it was composed of an interesting series of charnockites, which had not been recorded in that country before. One could see from the air that this range needed a precise examination, and the results of such examination were quite striking. He exhibited a photograph in which was shown the outlet of one of the major fjords on the coast at Nachvale and pointed out the distinction between the gneisses of the basement series of the country and some of the upper pre-Cambrian Ramah beds that Professor Coleman, of Toronto, when he visited that country for the Dominion Government, had recorded. There were almost horizontally flat-lying shales and quartzites on the old eroded upturned gneisses of the earlier pre-Cambrian period, clearly seen in the photograph of a dissected terrain.

He next showed some of the islands off the coast and, as a further indication of the difficulties with which aerial survey was faced, pointed to the thick mists that constantly hung over the Labrador Current. These islands were all features of this " drowned " topography of the east coast of Labrador. It was not a case of submergence only, as stated earlier, because there was plenty of evidence that the country was now emerging, and the expedition obtained proof in varying parts of the coast of old shore lines, in some places up to an altitude of 500ft. above sea level. One island which he indicated showed in a marked way one of the old shore lines. Here also there was evidence of a bar actually marking the outlet of what was once a fjord and was now a lake. Thus there were features of submergence, as well as emergence, which could be attributed to uplift of the land consequent upon the relief of its ice load.

With regard to the glaciology, the aerial photographs showed most definitely some very interesting features. The evidence was clearly brought out of the

result of the Pleistocene ice sheet that once covered a considerable portion of the country. One of the examples which he showed was at the extreme north of the country, one of the Button Islands at the entrance to the Hudson Straits. In this northern part of Labrador there were clearly brought out the gigantic striations, due to the gouging of the ice sheet as it made its way northwards towards the Hudson Straits, the direction corresponding to the foliation and strike of the gneisses. The resulting valleys were perhaps 50 to 100ft. in depth.

Another slide showed one of the settlements in the southern part of Northern Labrador, at Hebron, which was the base of the operations of this last summer. He made a flight from this place in 1931, and was able to get some interesting information with regard to the extent of the volcanic series of the Kaumajet mountains. This volcanic series, to its full extent, had not been known before, and during the flight from Hebron he was able to see that it was restricted to the Kaumajet mountains. During that flight, they were able to discover five new rivers and cover a considerable section of entirely unknown country.

His concluding slide showed the striking mountain group of the Bishop's Mitre which dominated the Kaumajet range.

What he had stated had merely outlined the work of the expedition in Northern Labrador, and he was afraid that it did not bear very much on the economic side of geology: deposits of economic significance were conspicuous in their absence from Northern Labrador. There were those who hoped and felt, however, that something economic in the way of geology might come from some part of Labrador before very long.

Dr. L. HAWKES: In 1930 he had taken part in an investigation of the value of aerial photography as an aid to geological survey in Northern Rhodesia. The country examined was approximately flat, and was one of the most difficult terrains in which to get at the solid geology—whether from the air or on the ground—as the rocks were for the most part covered by a thick soil blanket, which, in turn, was clothed with dense bush or long grass.

A strip of country 120 miles long and 2 miles wide, of which vertical photographs were available, was traversed, and this was divisible into three sharply-defined zones each with definite photographic characteristics. Zone I, flat country with even bush broken by large irregular grass areas, yielded rare outcrops of pre-Cambrian rocks. Zone II, also flat in which no outcrops were seen, exhibited a clumpy distribution of bush interspersed with grass and is possibly underlain by Karroo sediments. Zone III, gently sloping ground, was similar in bush cover to Zone I, but the grass areas were smaller and elongated, and outcrops of igneous and pre-Cambrian schists were abundant. The differences in the distribution of the vegetation of Zones I and III were not due to underlying rock composition, but were those between a flat and a sloping terrain. Zone II is a slightly depressed tract, and its bush characteristics are probably governed by special ground-water conditions, which in turn may be controlled in part by the nature of the rocks below. The two boundaries of Zone II are clearly marked in both " verticals " and " obliques " as straight lines trending north-east, and this tract was regarded as a graben. It was possible from the aerial photographs to map the fault boundaries of the graben for many miles.

Coming to details, he emphasised the value of the photographs in indicating the location of rock outcrops—especially in river courses where the white lines of waterfalls revealed the strike of the rocks, and also the probable direction of dip—*i.e.*, up-stream. He showed a photograph in which the strike control of a stream was demonstrated, and also the circumstance that a sharp bend in its course was governed by a dip fault. Successive stages in the evolution of meandering rivers were beautifully brought out in some of the photographs.

With regard to the main point of issue as to whether details of underlying rock distribution could be discovered aerially, vegetational areas could be distinguished and delimited on the photographs although it was impossible to map them on the ground, each area showing up by reason of some characteristic of height, composition or density of bush. If these differences were controlled by the soil, and by those characteristics of the soil which were determined by the nature of the parent rock beneath, then the vegetational map would be a reflection of the hidden solid geology. In his traverse it was impossible to test this directly owing to the paucity of rock outcrops, but an indirect test of some value could be applied. In those countries where the different members of a pre-Cambrian series were exposed they mapped as straight or sweeping bands with characteristic trend features, and if the vegetational belts showed similar dispositions, there was a possibility that they were geologically determined. In the strip traversed such banding was rarely observed on the photographs, but where present he accepted it as a probable indication of underlying rock structure—indeed, it would be difficult to suggest any other control. Many vegetational maps of Northern Rhodesia, however, presented a most irregular pattern and looked more like jig-saw puzzles than geological maps, and here one could not accept any paramountcy of geological control, for however complicated pre-Cambrian areas were they did not map in this way.

In 1928, Mr. R. Bourne published a vegetational map of a strip of Northern Rhodesia, a small part of which was common ground with a small part of Mr. Jackson's geological map of the N'Changa district, recently published.[17] The geological map showed rocks of widely differing composition in this area, and many of the boundaries of the rock formations there given coincided to an impressive extent with the boundaries of the vegetational areas in Mr. Bourne's map. Possibly Mr. Jackson had made use of the vegetational characteristics in fixing his geological boundaries—he had no information as to that—but even so he must have had evidence of the presence of the rock types shown. However, the speaker pointed out that the same vegetational type was present over basic intrusives, shales, and arkose, and the same over basic intrusive and dolomite, so that vegetational type was not here governed by underlying rock composition. Aerial photographs had been taken of the whole area of Mr. Jackson's map, and he suggested that a study of these in conjunction with the geological map would be instructive. He quoted the opinion of a geologist in Northern Rhodesia that "soil and vegetation boundaries are useful when working out a real geology, but unless controlled by the occurrence of rock outcrops that can be determined, they are likely to be very misleading."

Mr. Gill's paper was a valuable and fair statement of experience of the value of aerial photography to date. It was the work of an enthusiast, but if by that was meant one who wished to see every reasonable hypothesis tested before it was discarded, then surely they were all enthusiasts with him.

Mr. ROBERT ANNAN: This paper was extremely opportune at a time when the attention of mining engineers was being turned to the aeroplane as an adjunct in various ways to mining operations, and the author was particularly to be congratulated on the wealth of detail presented, whereby mining engineers might measure the value of the method as applied to their own particular problems. The cost, of course, was a matter of great interest, and could only be estimated within wide limits. One of the points to which he would like to draw attention was that for any aerial survey, or for the use of the aeroplane in connection with mining operations generally, it was necessary that there should be a reasonably accessible aerodrome. This affected greatly the cost or even the possibility of carrying out the work. Fortunately it was

[17] *Quart. Journ. Geol. Soc.*, vol. 88, 1932.

a difficulty which was becoming less acute as the range and reliability of the aeroplane increased.

In presenting so much detail, he thought there was a tendency for some of the principles to become obscure, and he hoped that after the discussion the author would favour them with a general summary setting out the main features. The point that he would criticise in the paper was the emphasis it placed on the use of this method for the reconnaissance of large areas, to the exclusion of the detailed study of smaller areas where mining operations were already in progress. The reconnaissance of large areas had been so well covered in the paper and by the remarks of subsequent speakers that he need make no further reference to it. The advantage of the aeroplane should be obvious. The area was covered in a short time, the detail was permanently recorded, and where the topography, the ground colouring, the vegetation, and so on, formed a guide, the method could be extremely useful. One feature of work of that kind which had escaped mention by the author or by any other speaker was, in jungle areas and the like, the location of ancient workings, which was very frequently a guide to mineralisation.

In known mineral areas where detailed study might give information as to the extension or repetition of orebodies, such problems were often related to faulting and shearing, which frequently had a more or less symmetrical character, and here again the aerial photograph might furnish clues to structural details and offer an excellent guide to prospecting and development.

The author had laid down two essential principles. The first was that work on the ground and from the air must always be carried on in conjunction; and, further, that the interpretation of the geology from aerial photographs was very largely a question of the systematic and careful examination of stereoscopic pairs. In other words, the aerial photograph was an aid to, and not a substitute for, accepted geological methods. Its outstanding advantage was the power which it conferred on the geologist to see all the features of an area at once. The interpretation of the photographs, if the general geology was known, was facilitated, but the details must be checked on the ground. He thought that previous speakers had emphasised that. In this connection the use of the stereoscope, to his mind, was essential. Having had some experience during the war of aeroplane photographs for topographical work, he had been frankly sceptical as to the value of the method for geological work, but the application of stereoscopy for this purpose had completely changed his point of view. The discovery and correlation on the ground of minor structural features involved a great amount of painstaking work, the value of which might be entirely lost unless the results were applied on an accurate topographical plan, so that distant features might be seen in their relation to one another and the general symmetry brought into view.

Aerial survey brought these points together, and the geologist could see both sides of the mountain at once. If, as often happened, there was a repetition of structural features, this was made evident on the photographs, and the geologist was enabled to link one feature with another in a way which could not be accomplished from the ground without an expenditure of time and money far in excess of the cost of the aerial survey. The mathematical accuracy of the survey was of secondary importance from the geologist's point of view; it was the picture which counted. With the stereoscope it was remarkable how the minor details of relief stood out. The shallow depression which was left on the surface by faults or shear zones was revealed in a striking manner, and the surface variations caused by alternating soft and hard bands of rocks were easily traced, not only locally, but for distances considerably in excess of what came within the view of the observer on the ground.

With this picture in mind, the geologist could go straight to the essential point, and any minor distortions in the photographs were readily corrected.

The author had remarked that " minor forms and rock outcrops " are frequently indicative of the details of dip and strike and of quite small breaks in the general structure. From the air their significance can be appreciated (chiefly from photographs) much more easily than on the ground.

That was the essence of the method as regards the study of small areas, and must be seen to be appreciated to the full. There was, however, just one word of warning. The art critic of *The Times* newspaper that very day, in dealing with the results of photography by infra-red rays, remarked that, as painters knew, it was exceedingly difficult to limit observation to what was actually seen. In interpreting aerial photographs it was, to the speaker's mind, essential that any deductions should be checked by actual field work.

With regard to the form of the photograph, the author expressed preference for the contact print. This placed a limit on the largest permissible scale without undue distortion. For his own part he found the density of detail in a scale of 1 :10,000 rather confusing, and he preferred enlargement to about double that scale. For the general reconnaissance of large areas the smaller scale was, no doubt, essential, but for detailed study of small areas he doubted whether the fine points which might indicate structure—he was speaking now of the indications of faulting or shearing—would come out as clearly on the scale of 1 :10,000 as they would on a scale of 1 :5,000. The aerial survey recently made by the Wanderer Consolidated Gold Mines, Ltd., of Rhodesia—the first prints of which were on view that evening—adopted, as the first stage, a strip 5,000ft. wide by 16,000ft. long. This was photographed from a height of 8,000ft. with a 10in. lens, giving a scale approximately of 1 :9,600. The prints had been enlarged to double the linear dimensions, bringing them to a scale of about 1in. to 400ft. The cost of this work up to that stage was £192 in South African currency. The work was carried out by the Aircraft Operating Company of Johannesburg. As the study of the photographs was not quite complete, he must refrain from comment for the present beyond expressing the view that the results gave every promise of valuable guidance for future development. He would have liked to have gone further, but the work was in the hands of the consulting engineer in Johannesburg, and as the survey was being extended and was not complete, it would not be proper for him to do more than indicate some of the main features. Certain geological features could be seen with the greatest distinctness, and the prints would give members an idea of how much detail could be brought out in the way of structure. If anyone was interested enough to look at these photographs after the meeting they could see that for themselves without any guidance from him. A number of interesting features had been disclosed by the topography. He might add that the Wanderer was situated in a part of Southern Rhodesia where the relief was more than usually marked for that part of the world.

In conclusion, he affirmed his conviction that the aerial photograph had a definite application, not only to the reconnaissance of large areas, but to the solution of those problems which mining engineers so frequently encountered in endeavouring to make up their minds as to what were the prospects of finding extensions or repetitions of known orebodies. He hoped that that aspect of the business would not be overlooked. The brief experience he had had with the photographs which were on view that evening convinced him that there was quite a field of opportunity in that direction also.

Mr. H. HEMMING: The paper was all the more welcome as coming from one who was not an airman, for with one or two exceptions airmen had had to cry their wares themselves.

He was glad that Mr. Gill referred to the interesting work that Mr. Ray Bourne carried out in connection with the original survey in Northern Rhodesia. Mr. Gill's paper made a very good follow-up to Mr. Bourne's valuable pioneer work.

Mr. Gill had referred to the work carried out in 1927 for the Rhodesian Congo Border Concession, Ltd., by the Aircraft Operating Co. Although that work might not have been productive of the geological results hoped for, he suggested that this was due to the experimental nature of the work. With to-day's knowledge the result would have been very different, and he believed that Mr. Bourne's work and that of Mr. Gill and of other speakers supported his contention.

The Government of Northern Rhodesia and all interested in aerial surveying, owed a debt to the Rhodesian Congo Border Concession Co., for having had this work carried out at the suggestion of Mr. P. K. Horner. The results of the survey had been a great benefit to the Government, for the expedition was able to carry out surveys for them on specially attractive terms. Actually 400 miles of the Zambesi River and its tributaries were photographed, a number of townships were surveyed, a Boundary Commission was supplied with photographs, and finally an area of 63,000 sq. miles was mapped on a scale of 1 :250,000.

The author had referred to the important question of cost. Cost, of course, depended, apart from the weather, on the exact nature of the surveys to be carried out and the scales required, and also the services to be rendered by the survey company. In order to prepare estimates for aerial survey work it was essential to know certain details, of which the following were the most important:—

(1) Size and position of the area or areas to be surveyed.
(2) General description of the topography.
(3) Are prints only required? Vertical or oblique or both?
(4) Are prints and mosaics required?
(5) Are maps required?
(6) What scales are required for 3, 4 and 5 above?
(7) Does any form of ground control exist? Is this control to be supplied by the employers or by the contractors?
(8) What sort of accuracy is required?
(9) Are contours required? If so, at what intervals?
(10) What facilities exist for the operation of aircraft and the general housing of the expedition? Are these facilities to be supplied by the employer or by the contractor?
(11) General particulars of the meteorological conditions of the area, particularly in relation to cloud and mist.

The cost to the Government of the aerial survey of 63,000 sq. miles in Northern Rhodesia was £63,000—that is, £1 per sq. mile. The photography was completed in three months and the maps in 15 months. It would have taken many years to carry out the work by ground methods alone and the cost would have been prohibitive. The company had to provide their own astronomical control. By having had designed and constructed a special aerial survey aeroplane to their specification they were able to do the whole area from two aerodromes. Reconnaissance maps to a scale of 1 :250,000 were prepared from parallel strips of vertical photographs which were run across the area 20 miles apart, while the intervening spaces were mapped by oblique photography.

With regard to the author's estimate for a controlled mosaic on a scale of 1 :50,000 of 50 sq. miles at £30 per sq. mile, such a small area could only be tackled at that figure if an aerial survey expedition was in the neighbourhood. In order to reduce costs it was essential that large areas should be tackled.

For instance, it was estimated that certain states in South America, covering an area of 401,805 sq. miles, could be mapped from vertical photographs on a scale of 1 :50,000, to include 25 m. conteurs, at a total cost of £1,515,000, that is, £3·77 per sq. mile, the survey taking five years to complete.

At the other extreme in cost per sq. mile, a contract was recently completed of a large scale city survey assisted by aerial photography. The area on a scale of 1 :1,000 cost £2,500 per sq. mile.

In his opinion, in order to get the best out of aerial survey, it was essential that operations should be conducted on a mass-production basis. Big areas were required in order to secure small costs. The aerial survey photographs contained such a mass of data relating to the economic possibilities of the territory under survey, quite apart from topographical data, that it was essential that all those interested in the economic development of the area should come together under some co-ordinated scheme.

In the past there had been an enormous wastage through aerial survey photographs only being used for one purpose when they had had a great deal of valuable information in them for a variety of purposes. Provided satisfactory co-ordination of Government and private interests could be secured, he was convinced that aerial survey could render immediate and most valuable service to the economic development of the Empire, the Mining Industry and of British trade generally, and he looked upon the present paper as a great help towards the realisation of this ideal. He added that proposals for a scheme for the co-ordination of interests had already been submitted to the various departments of Government. The proposals envisaged the creation of a national organisation which would have funds available for assisting in the development of aerial survey work, and for securing the co-ordination of interests already mentioned. Such an organisation would be complementary to, and not competitive with, the existing operating companies. He hoped that by the creation of such an organisation the author would be able to secure the funds for carrying out the research that he referred to near the end of his paper.

Mr. Gill had compared photography with visual reconnaissance and had said that the eye, being swivelled, at all times had a wider view than the camera can record in a single photograph. The present speaker believed that very shortly the camera would be able to obtain an all-round view at a single exposure by the use of several lenses. Such cameras had been built, and he thought that the experience gained with them would result in a suitable British camera being produced very soon. There was certainly a call for it.

Professor V. C. Illing: He had not come that evening with any prepared contribution to the discussion, but merely to enjoy the paper and the subsequent remarks, and he had done so. Perhaps he might illustrate his own association with aerial work by a story. Some ten years ago he was working in the bush near Maracaibo, on the western plains of Venezuela, where most of the ground was covered with heavy forest. After working in that zone from six weeks to two months without seeing a single outcrop, the cry for a bird's-eye view became somewhat insistent. Just on the edge of the plain there was an escarpment of sandstone and, making for this, he saw a lovely green spot away above. Such a spot seemed worth attaining, because of the outlook it would afford. His companion and he spent the better part of a day climbing to that spot, only to find that that lovely green verdant " lawn " was grass about 15ft. high and a view impossible. Not long afterwards the speaker was able to fly over the same area, with the result that in something like three hours he succeeded in doing what he had been attempting to do unsuccessfully for eight weeks, namely, the tracing of a band of sandstone for 20 or 30 miles through the country, and getting a general idea of the lines of structure. That was the kind of thing to which aerial survey lent itself admirably. It gave one the power of rapid

reconnaissance which allowed of the lines to be taken broadly through a country.

In the photographs which he took on that occasion, there were small white dots in the bush which might have been small volcanoes, so he determined to go again and explore. Lines were cut through the bush, but when they arrived at the place indicated, they discovered only a crop of anthills.

The two experiences pointed a moral. Geologically it was essential to get a bird's-eye view, and a broad outlook before starting to deal with details. The aeroplane presented to the geologist far and away the best means of this rapid reconnaissance. But when all that had been said and done, he, like most speakers that evening, would emphasise that the essential evidence was obtained only by covering the ground on foot. From the point of view of geological work, the aeroplane survey gave a broad guidance as to what to look for, and saved one's time tremendously; but the detailed work of following out what it meant was still essential and could only be done on the ground.

Mr. Ray Bourne: There was no question whatsoever that the complete interpretation of aerial photographs could only be made on the ground, whether one was looking at the photographs simply from the geological point of view or with a view to interpreting the vegetation. The distribution of vegetation was primarily governed by the climate, secondly it might be affected by the soil, and incidentally by the geology. At the same time, it was constantly modified by man. He had had the advantage of studying large numbers of photographs taken in different parts of the world, and it was amazing to find what a small portion of the earth's globe had not been cut over at some time by man. Some of the most striking differences in vegetation were certainly due to human intervention. Therefore, when one came to look at aerial photographs, here at home instead of on the ground itself, one had to be very careful as to what was inferred. When he started looking at these photographs he was much too sanguine as to the number of lines indicating geological changes. That might possibly have made the geologists who considered his reports extremely sceptical if subsequently they found that some of those lines were of no geological significance. What was really necessary to his mind was co-operation in the field. The ecologist wanted to know about the soil and geology, while the geologist needed help in the interpretation of the vegetation.

The President (Dr. Sydney W. Smith): The discussion had been most interesting and profitable. The paper and discussion taken together must, he thought, have a broadening effect on the outlook of mining men towards all matters relating to the location of mineral deposits and to their geological associations. This was well illustrated by the quotations given by the author from writers who had described the usefulness of the aerial view. The author had quoted Crawford and Keiller as saying, for example, "The distant view is necessary to convert chaos to order." Professor Illing's remarks were very much to the same point. To illustrate this by analogy, Messrs. Crawford and Keiller recalled how the half-tone picture seen through a lens became "a meaningless mass of blurred dots," but if one held it some distance away and looked at it with the naked eye it became a picture again. The author had quoted another writer as saying that aerial observation compelled a truer perspective and broadened the mind to think "regionally." They would all agree that these statements were very true. Those who had had opportunities of aerial observation, or, like Mr. Odell, had climbed to great heights, fully realised its value.

Contributed Remarks

Brigadier St. J. L. Winterbotham (Director General, Ordnance Survey Office, Southampton): (1) The word "aerial" is not used in British practice in connection with air survey. The fact is that the word aerial reminds one some-

times of Milton, and sometimes of broadcasting, and we have found it on the whole better to talk of " air " survey.

(2) Shadows of forest trees are referred to. Very often it becomes a matter of the greatest difficulty to study the sub-soil through forest trees and the shadows they cast. In these cases of difficulty, it is often advisable to place the photographs in the wrong sequence and therefore to obtain a pseudo-stereoscopic effect (that is, bringing the ground above the level of the tree-top) —detail will be found more clearly in this way.

(3) Where the section begins upon the interpretation and use of air photographs by the geologist. He would like to refer you here to " The Manual of Map Reading, Photo Reading and Field Sketching," dated 1929, issued by the War Office and published by H.M. Stationery Office. In this manual the article on photo reading (from pp. 79 to 95) will be found, he thought, the clearest and most valuable exposition on simple interpretation and mosaicing (for which see Appendix IV, p. 150). Particular attention might well be directed to the improvised stereoscope as illustrated opposite p. 94. Where it can be acquired, there is no doubt that the Barr and Stroud topographical stereoscope is the most convenient model both to carry and to use. There occur occasions, however, when one may be quite unprepared, and the improvised stereoscope, to which I refer, can be made in half-an-hour by anyone who has magnifying glasses with him.

Undoubtedly this manual should be referred to in any bibliography on the subject.

(4) A note on how to hold the photographs is given in the paper. It is not, he thought, quite adequate. There are many occasions on which it is impossible to verify by merely turning the photographs about when relief is stereoscopic, and when it is pseudo-stereoscopic. The commonsense of the question is clear. The shadow which appears on the photograph must lie in the direction opposite to that from which the light falls on the photograph. As the man who holds the photograph prevents the light falling from behind him, the shadow should, therefore, fall towards him.

(5) Contouring[18] on air photographs is referred to, and in connection with it the use of rod-men is suggested. Generally speaking, in the country where air photographs are being used for geology, there will be no previous spirit-levelling and no very good vertical control. Under such circumstances the contouring cannot be either absolutely or relatively of a high order. It will be found in most cases adequate to use aneroid barometers, either singly or better still in batteries, not forgetting to study their response to daily variations. That subject is briefly treated in the same manual on map reading to which reference has been made; pp. 132 to 138.

In contouring with a Barr and Stroud topographical stereoscope, it is necessary only to secure the relative heights of tops, bottoms, and occasionally breaks of slope. The rest is a matter of stereoscopic interpolation.

Mr. S. O. Hatton: As an introductory paper on the subject of aerial survey in relation to economic geology, Mr. Donald Gill has made out a good case, and has achieved the objects of his paper in relation to points (1), (4) and (5) particularly, but it leaves room for yet another communication from the author in the future to establish in no mistaken terms, rather than on broad grounds, the intimacy of relationship of " aerial survey " to the economic geology of the type that is so vital to the needs of the profession of mining and metallurgy.

No doubt the future development of this " new aid " will be in the more accurate interpretation of " vertical " rather than " oblique " photography, which tends to be more general in its scope, as compared with the exactness

[18] In this connection, see the " Manual of Map Reading, Photo Reading and Field Sketching," pp. 120-128.

of picture and detail which one must naturally expect (as a bird's-eye view) from the former.

The author is undoubtedly on firm ground when he states that " making purely topographical maps . . . is of no direct concern to the geologist "; but he was afraid he must rule out any attempt at accurate contouring, even at large intervals, or of accuracy in the establishing of topographical heights, which must be left to ground surveying, and which is of some concern to the geologist. Mere " relativity " is useless. The geologist can only infer from the photographs the nature of his terrain, and the better the picture, the more hope there is of his inferences being correct and helpful for his ground work with hammer and clinometer. All this therefore points to the highest quality of pictures, and it would be " *ideal* " to obtain them by some advanced method of colour photography of a fairly reliable order, which would help to differentiate between belts, bands or tracts due to faults and rock outcrops, etc., and others due to mere change in colour of soil *or* of sedimentary formations. After all, the case at present is one of interpretation and juxtaposition of colour.

The modern panchromatic film,[19] *or* spectrum plate, has been brought to such perfection, that its employment for three-colour work is, as shown by the author, both practical and convenient. It has been still further improved by the *tri-pack*[20] process, but at about three times the expense of ordinary sensitive film, and *hey presto*! as he wrote *The Times* Engineering Supplement of the 4th November gives hint of more recent work, making possible cinematographic colour photography, which has arrived.

Owing to the necessity of using a stereoscope for three-dimensional analyses of the photographs, as opposed to the two-dimensional, or plane look, in aerial survey work, the future might yet see a further advance by the use of stereo-colour cameras for aerial geological surveys, for to quote Dr. A. N. Whitehead[21] " It is no paradox to say that in their most *theoretical moods*, they may be nearest to our most *practical applications*." The aerial view has come to stay.

The importance of aerial survey photographs was brought home to him very forcibly in connection with survey work in the Jordan Valley and on the Trans-Jordan mountains for the proposed Haifa to Baghdad railway. To say the least, it helped to give the best and cheapest location in the least possible time, through wild, dangerous and extremely difficult country; but, as ground surveyors, they preferred their own levellings, which had been carried through accurately at great odds for great distances, to any airy heights recorded by the camera; for, on one occasion, without prejudice, the discrepancy of levelling between " aerial survey " and " ground survey " was measurable in hundreds of feet. This error, however, need not necessarily have been fundamental, as was proved to be the case, and the " ground survey " figures in that instance were retained and verified as more accurate by a reinvestigation of the air work from some well-known datum point.

Apart from the topography, the general tectonic and physiographical features stood out boldly with a marked differentiation in line and shadow of hills, valleys, cultivated tracts, and desert wastes; and the marking out of geological features was broadly noticeable.

No doubt the spotting of the mineral *dambos* in the copper belts of N. Rhodesia, as mentioned by Mr. Gill, is proof of the usefulness of aerial survey, as oil geologists have also found in regard to the discovery and search of mud volcanoes, some of which, near Baku,[22] are 1,300ft. in height, while those of Transylvania, in Roumania, are seldom over 30ft. in height; for Redwood states

[19] " Photography in Colours," by G. L. Johnson, M.A., p. 20. " Colour Photography," by Capt. O. Wheeler, F.R.P.S., p. 51.
[20] " Colour Photography," by Capt. O. Wheeler, F.R.P.S., p. 132.
[21] " Introduction to Mathematics," by A. N. Whitehead, Sc.D., F.R.S., p. 100.
[22] " Handbook of the Petroleum Industry," by D. T. Day, Ph.D., pp. 6-7, p. 162.

that " in Russia and in India the relationship between petroleum and mud volcanoes is very noticeable." But, taking the Rhodesian case, such features in other countries would not always necessarily indicate rock outcrops or fault-planes, for alluvial and recent sedimentary formations may exist as a heavy blanket on the country rock *or* sub-strata, as, *e.g.*, in the Gold Coast, and the colours may merely indicate different types of vegetation not related to rock or fault; nevertheless, who knows, but that through the agency of aerial surveys as applied to economic geology in the not too distant future, some petroleum or mining geologist on the look out for mud volcanoes or other geological fault-finding may not actually make the remarkable discovery of locating from the air the real " Ophir " of King Solomon's mines.

Dr. ARTHUR WADE: He enclosed particulars of a work[23] dealing with aerial survey not included in the bibliography given in Mr. Gill's paper. Further additions to Mr. Gill's list are made possible by a study of the references given in the text of the work quoted.

In the year 1924 use was made of photographs taken from an aeroplane by officers of the Queensland Geological Survey acting under instructions from Mr. B. Dunstan, the then head of the Department. Structures in Central Queensland which had been puzzling to the geologist working on the ground were easily unravelled when the photographs were examined. This, so far as he knew, was the first occasion on which an aeroplane was made use of for the special purpose of solving a geological problem in Australia. In the following year he advised a Company, whose surveyors were mapping geological structures in N.S.W. in connection with the search for oil, to have aerial reconnaissances made of their territory. This was done but, owing to inexperience of such work, the results were not very satisfactory. As a result of this work he came to the conclusion that success depended very largely on the skilful use made of shadows and that flights should be made in early morning or late afternoon to obtain satisfactory results. Further, some of the photographs were taken at too great a height to be of much value for detail, and it was apparent that the height from which photographs and observations were made should be varied according to the object in view. Zuber, in the paper referred to, gives valuable particulars based on his own experiences in this matter:

" L'altitude la plus propice pour les explorations préliminaires varie entre 600 et 1,000 mètres. Pour les détails on arrive aux meilleurs résultats en prenant 200-400 mètres, pas plus. Les grandes hauteurs (1,500-3,500 m.) ne servent qu'à observer les grands traits structuraux; la photographie perspective ne réussit que difficilement à cause des conditions atmosphériques spéciales. A ces hauteurs on travaille bien avec l'appareil aérophotogrammétrique." (p. 426.)

Mr. Gill stresses the necessity for stereoscopic pairs of photographs. In his experience, some of which has been gained during flights made within the past three years, this, though helpful, is not at all necessary for the determination of geological structure, especially where height and time have been well chosen. Photographs in his possession show geological structure quite clearly and in great detail without the use of stereoscopic effects.

After all, these " aerial surveys " (he did not like the term) are as old as geology itself. Every field geologist has made use of the mountain top, an escarpment, or even a tall tree, for just those purposes for which an aeroplane is now used. The aeroplane gives mobility and the power to vary the height and angle of view almost at will; refinements in aerial surveying enabled them to make topographic maps of difficult country in a minimum of time. In these directions the use of the aeroplane has carried us not only to higher but to more efficient levels.

[23] " Methodes d'Application de l'Avion et de la Photographie aux Recherches Geologiques." Dr. Stanislaw Zuber. *Mem. presenté au Congres International des Mines, de la Metallurgie et de la Geologie Appliquée.* VIe Sess. Liége, 22-28 Juin, 1930, pp. 425-430.

Mr. J. H. Goodchild: The remarks in the interesting section on "blankets" deserve close attention, otherwise an important link between the aerial view and ground geology may be overlooked.

Superficial limestone, clay, sand, or laterite, when seen as partial blankets about high ridges, are good guides in any ideas we may frame about the effect of the greatest of all blankets—the sea.

Laterite is a contact or interface growth between the atmosphere and solid land. Surely the air view should enhance this conception of it. Then limestones and sands have similar oxide concentrations at their lower contact. Hence they are illustrations of the kind of chemical effect to be expected when "earth movement" or "earth process" lifts such blankets, either through the atmosphere or through sea-water.

L = *Limestone.* B = *Blanket.* C = *Contact deposit.*

If now, in the same partially blanketed region, there are contact deposits along the dip of inclined older strata, there is striking evidence of internal growth in the history of the emergent ridge. Instead of a few interfaces one imagines innumerable ones leading to effects called "regional."

When Milner says that the air view helps towards thinking "regionally," he doubtless means historically also. Yet it may not be practically possible to do so in old-fashioned terms. Hence these remarks connecting laterite with ore deposits and calcareous blankets in half-desert country are not mere fancy. They refer to a practical means of giving geochemistry its natural place as mediator between stratigraphy and geophysics.

It is hardly permissible to pursue this line of thought very far in the present discussion, but it leads to a dynamic view of orogenesis and growth of land forms in which the salt sea is not regarded as a mere blanket. From Suess downwards this is often the case among geomorphologists and geophysicists.

Considering the chemical implications of stratigraphy rather than the residual beds so prominent in structural survey, it is not difficult to imagine broadly the growth of granite or porphyry, provided a sufficient series of heavy metal concentrations is borne in mind. Stratigraphy by its own methods provides certain historical information, but ideal "sedimentary rocks" in order of superposition are something apart from the interactions of matter, where there may be, for instance, a slight heave of the land at every tide. The "rock" unit can be abandoned temporarily in favour of ideal morphological units which may be said to grow in a field of potential. This is the way in which we speak of a "concretion," and where any kind of symmetry or ordered arrangement is discernible, it can be tried for what it is worth. Visible contacts or interfaces, whether under blankets or vertically disposed, annihilate the "crust" notion and open the way for dynamical treatment.

Remembering the recent discussion of Mr. William's paper on Huelva, particularly the remarks of Mr. G. W. Gray, he suggested that a traverse from the Atlantic to the Mediterranean across the south of Spain, would probably yield more important results than could be so easily obtained in any other part of the world. What features in the west would be advantageously shown is a matter for an expert in aerial survey. In the east, however, two things would probably come out well in oblique views. First, the ranges with schistose cores partially blanketed by Tertiary clays and limestones. Secondly, the Triassic

limestones flanking the ranges and emergent with the schists from the blanketed areas. The numerous mines are full of illustrations of the internal changes attendant on "earth movement" and the Mediterranean Sea, which has so many similar areas under like climatic conditions, is there close by.

Spanish engineers, of course, know the district well, but collaboration would bring in experience from a wider field. If the Royal School of Mines extended thus far the investigations already begun, an aerial survey organisation might find it worth while to take the matter up gratis, seeing that the Mediterranean region occupies such a unique position in the world, and such important theoretical results might confidently be expected.

Mr. G. V. Hobson: As a result of some experience of geological surveying, and after reading Mr. Gill's paper, he was satisfied that there is a definite, if possibly somewhat limited, future before what he may perhaps be permitted to call "geo-aerial surveying," both by direct observation and through the medium of photography.

Whilst working in the Northern Shan States of Burma, he made use of certain factors that he was satisfied could have been equally well, or better, used from the air. To mention only a few: the contact between the Tawngpeng granite and the Chaung Magyi series could be readily mapped by the change in topography, coupled with a change in soil and general fertility. Similarly, with the basic inliers that occur in places. The Namhsim sandstones, above a certain minimum elevation, are characterised by the growth of pines, not to be seen elsewhere. The Plateau limestone has its own characteristic topography and usually supports a sparse thorn scrub or long grass; where covered by later formations, such as the Rhætic, there is a characteristic change in colour of the soil, greater fertility, and bamboo jungle (as opposed to odd growths) is almost confined to these parts. Last, but not least, he ventured to say that no mineralisation will be found in this area that the Chinese had not examined in the past, and evidences of their efforts would generally be visible from the air.

As a result of a long and arduous camp season he mapped about 200 square miles of this country. Mr. Gill mentions that in an aerial reconnaissance of forests in Burma a total of 230 square miles was covered in an hour. Such a rate of progress could not be maintained in geological work, in the area he described owing to the necessity for ground control. It may be said that natural landing grounds do not occur, and key areas would have to be examined by the normal methods of geological traverses, to maintain ground control.

Detailed work such as the collection of fossils, measurement of dips, etc., and the actual examination of old workings would still have to be done from the ground. Nevertheless a fairly comprehensive reconnaissance map could, he believed, be prepared at a comparatively rapid rate.

He need hardly recall the fact that the re-discovery of Bawdwin mine resulted from observations of the old work done by the Chinese, and in particular of the enormous accumulations of their old slags. These would have been very evident from the air, and in this connection he would like to add to Professor Boswell's interesting observations with regard to inaccessible places. He would use the term inaccessible not as Professor Boswell did as referring to physical factors, but as referring to the activities of man, *i.e.*, as regards observation over hostile country—and there are still a few such places, even in these times of peace.

In north-eastern Burma there is a persistent rumour that there exists an enormous lead-silver deposit in the Wa country. This country is inhabited by headhunters. An aerial reconnaissance over this area would go far to settle whether there is, or is not, any foundation in this story and pave the way to a decision as to whether an expedition should be financed to make investigations, if sanction could be obtained, and when the world is ready for additional lead-silver-zinc resources.

Again, whilst in Kutkai he met the Civil Officer who had been in charge of two armed expeditions into the unadministered areas of the Hukawng Valley, Upper Burma. As a result of their conversations he convinced him of the great utility of having a geologist attached to such an expedition. The Director of the Geological Survey of India favoured the idea and it was eventually adopted. How much more useful would it have been if, as a result of a preliminary geo-aerial reconnaissance, the geologist had been able to offer advice as to the most suitable route to take, from a geological standpoint, other things being equal.

Dr. J. Coggin Brown: Accepting the invitation of the author to add to his bibliography of references bearing on aerial geology and cognate subjects that are likely to be of interest to the geologist, attention may be directed to a note by the late Sir Henry Hayden in the General Report of the Geological Survey of India for 1919. In the portion dealing with the deputation of Dr. (now Sir Edwin) Pascoe to make a geological examination of parts of Mesopotamia during the winter of 1918-1919, the following statement occurs:[24]

"By the courtesy of the Flying Corps, Dr. Pascoe was taken for a flight over the Jabal Yawan, partly to visit country whose more intimate acquaintance the hostility of local tribes rendered it inadvisable to make on foot, and partly to test the value of aeroplane reconnaissance for geological work. With regard to the latter the result was on the whole disappointing, though an excellent bird's-eye view of the structure of the anticline was occasionally obtained. The Fars beds could be recognised even at 1,000ft. altitude, but their boundaries could not be observed with sufficient approximation to make this method of surveying of any great use."

Sir Edwin Pascoe's own account of his observations, though dated the 6th January, 1919, was not published until 1922, and is to be found in his "Geological Notes on Mesopotamia with special reference to the Occurrences of Petroleum." On portions of the geological map of the country between Mosul and Sharqat which forms Plate 3 of this memoir, the words "Geology by Aeroplane Observation" appear.[25]

Mr. Leslie H. Ower: Although much interested in the paper on aerial geological surveys, he had had no actual experience in reading aerial photographs.

Much of Northern Rhodesia has been surveyed from the air, but the field geologists prospecting for the Companies are only supplied with ordinary topographical maps compiled from this source. The "dambos" in this country often represent accumulations along lines of dislocation, peneplaination being still in progress. When attempting to work out structure from the limited data obtained by actual traversing, these aerial maps, indicating the correct outlines of the "dambos," are of assistance.

Applying the knowledge gained from reading aerial photographs to the study of lunar geology might be thought to be entirely outside the province of the economic geologist, but surely some of the problems of fundamental geology can be tested by studying the surface of the moon, devoid of denudations or accumulations. The large telescopes have enabled the topography of the side of the moon visible to us to be better mapped than some parts of the earth. Even to the ordinary geologist, many structures on the moon are quite plain, and if lunar photographs were studied by geologists expert at reading aerial photographs, a wealth of detail should become available useful for tracing out similar structures masked on the earth.

Reply to Discussion

A great many interesting points have arisen in the course of the discussion. It has been an advantage to have contributions from men with such widely different outlooks as, for example, Professor Boswell and Mr. Odell on the one

[24] *Rec., Geol. Surv. Ind.*, vol. li, p. 21. (1920.)
[25] *Mem., Geol. Surv. Ind.*, vol. xlviii, pt. 1, pp. 19-20. (1922.)

hand who emphasise the importance of oblique photographs, and Mr. Annan on the other hand who agrees with me closely in his appreciation of the stereoscopic pair.

Oblique Photographs.—I am glad that Professor Boswell and Mr. Odell concentrated largely upon the use of oblique photographs, since they were perhaps not adequately considered in the paper. Those members who attended Major Day's lecture the week following the discussion of my paper had a further opportunity of seeing how prominently some geological features can be brought out in obliques.

Professor Boswell made out an excellent case for the use of oblique photography under special conditions. In highly-dissected country of the Alpine type, where steep and inaccessible slopes are combined with complicated geological structure, the use of oblique photographs is certainly indicated. Their use for the routine observation of changes in Alpine glaciers is extremely interesting, and is an economic application that was entirely new to me.

Mr. Odell's slides illustrated very clearly the utility of oblique photographs in giving information about the recent geological history of a mountainous and glaciated country like Labrador. The glacial geology, including especially the "gouging" of valleys parallel with the strike of the gneisses, the drowning of the topography followed by emergence, and the different appearances of formations of different ages, were well illustrated in the photographs.

In less highly-dissected regions, important geological structural features may show prominently in obliques, examples being the *graben* fault shown by Dr. Hawkes in one of his slides, and shear-zones appearing in some of Major Day's slides already mentioned.

Oblique photographs can be divided into two important classes from the point of view of the geologist: (1) those taken in the course of an organised survey for mapping purposes, and (2) those taken casually in the course of reconnaissance flights. The difference between the two classes is important for this reason, that in the first class (*survey obliques*) the air station from which the exposure is made can be determined indirectly, and the geological information appearing in the photograph can be transferred to the map with the same degree of precision as the topographical detail. This is done in the Canadian and Rhodesian methods of survey by means of special perspective grids and in the Miller method by intersections (bibliography, Section 1). The second class (*casual obliques*) suffer from the defect that the position of the air station from which they were taken is entirely unknown and cannot be determined and there is, thus, no means of transferring geological information from them to a map except sketching by interpolation from the detail appearing both in the photograph and the map. In reconnaissance work maps are liable to be either non-existent or totally deficient in detail adequate for this purpose. Casual obliques, therefore, while they may be extremely useful for illustrating or elucidating structures, are of limited application for geological mapping. Where they can be most useful is in conjunction with visual reconnaissance, to act as a "photographic memory" for the observer of some aspect which he wishes to catch and record permanently.

In many types of country a single oblique photograph will act as a better illustration of the physiography and of the geological structure than a single vertical photograph. But if vertical photographs are being employed at all the will nearly always be available for stereoscopic use, and in the stereoscope both the physiography and the geological structure are revealed in a manner that no oblique photograph can approach. One defect of obliques was illustrated clearly by one of Professor Boswell's slides: this was of a series of parallel ranges composed of stratified rocks in Central Australia and although the strike of the rocks was indicated with the utmost clarity, it was impossible to determine whether the dip was toward or away from the observer: such a

position would not have arisen if a stereoscopic pair of verticals had been available.

Turning to the remainder of Professor Boswell's discussion, I should like to confirm that the shatter-belts controlling the formation of the Victoria Falls and gorge can be traced on the photographs through the country to considerable distances from the river.

On the question of the relative visibility on photographs of recent and old faulting (in which term I should like here to include, for the sake of comprehensiveness, other types of rock fracturing than just simple faulting), I am obliged to disagree. While faults which have moved recently (such as the San Andreas fault) show well on photographs by reason of topographic features created by the movement, and which have not had time to be levelled off, there is no doubt that very old fracturing (even dating back to the pre-Cambrian) is frequently visible on air photographs. Some examples may be given: (1) The mineralisation at Great Bear Lake is in pre-Cambrian country and is, as I understand it, associated with shearing which is itself of pre-Cambrian age. These mineralised shear-zones were clearly seen in some of Major Day's slides, and were much more clearly seen stereoscopically in the vertical photographs which he had on the table. (2) In the Barberton district of the Transvaal the mineralisation with sulphides and gold is associated with rock-fracturing, which dates from the intrusion and consolidation of the old granite. This granite is pre-Cambrian, and not late pre-Cambrian at that, since it is older than the Transvaal system, which rests upon it unconformably. In the Sheba Hills, near Barberton, many of the mineralised fractures are followed with the greatest ease under the stereoscope. (3) The thrust-fault at the northern end of the strip of Wanderer photographs exhibited at the meeting would almost certainly be held, by Rhodesian geologists, to be a fault of pre-Cambrian age, probably dating from the intrusion of the granite. This fault was very evident on the photographs, *even without the use of the stereoscope*.

I should like to advance the following explanation: Once a mass of rock has been broken in any way by earth-movement, causing faulting, shearing, the development of local schistosity, etc., the texture of the rock along the line of disturbance will never again be exactly the same as it is in the unbroken rock. The fracture (fractures) may remain unfilled or it (they) may become the locus of some kind of rock-alteration or mineralisation. Whichever happens, the texture is in some way or another permanently different along the line of fracture or disturbance. Such differences may show up on photographs as a slight break in the topography resulting from difference in resistance to weathering, as a slight change in the soil-colour, or as a slight difference in the vegetation resulting from a difference in soil-moisture conditions. Old fractures will not be seen in photographs taken in every country: along with other features they are seen in those countries, which, for one reason or another, are favourable to the expression of the geological structure in a manner that can be photographed.

With regard to contacts between rock formations, it is quite true they frequently appear less prominently than would be expected; on the other hand, details of bedding may in some instances be closely followed, under the stereoscope.

On the question of " trusting " aerial views, I think in the case of each individual geologist, and probably anew for each different type of country in which he works, such " trust " must be developed as the result of experience. The paper postulates that the aerial work and the ground work must always be carried on in conjunction, and that the intention of aerial geology is to aid the geologist on the ground and not to supplant him.

On the question of "obtaining and relying on small details of earth features," my position is that such are frequently visible and alignable on photographs when they would be passed unnoticed by the geologist on the ground; that they act as pointers to relatively minor features of the geological structure; and that, as they may therefore have economic significance, especially in relation to ore deposits, they are worthy of consideration.

Mr. Odell's interesting contribution is largely dealt with in the discussion of oblique photographs above. Since his obliques were taken in the course of survey work for map-making, he was doubtless able to use them directly in the geological mapping of such of the geology as was visible in them. The tendency for glacial striæ and valleys to follow lines of weakness, such as the strike of gneisses and shear zones, demonstrated both in Mr. Odell's and Major Day's pictures, prompts the comparison between ice-sheet glaciation and the reagents used by metallographers and petrologists for etching polished specimens for study under the microscope: the structure is revealed in both cases, to the eye or to the camera.

Dr. Hawkes's valuable statement of his conclusions regarding the possibilities of aerial geology in Northern Rhodesia near the Copper Belt is the first authoritative published pronouncement from a geologist, and is welcome. Thanks are due to the Colonial Office for permitting the release of this information, rather than that it should undergo slow fossilisation in the archives. The difficulty of satisfactorily doing geology on the ground in parts of Northern Rhodesia is best appreciated by those who have tried it. Dr. Hawkes's opinion, though guarded, seems to be that vertical photographs could be of definite assistance in country of this kind.

It appears that important structural breaks, such as his *graben*, can be recognised and mapped directly from both vertical and oblique photographs (he was using survey obliques), whereas the geologist on the ground would have considerable hesitation in defining precisely the lines of the faults, in the first place, and a great deal of hard labour in putting them on the map.

On the vertical photographs the rare rock-outcrops are indicated to the geologist and (to all intents and purposes) mapped for him, while outcrops in streams are defined as to strike and in some cases direction of dip. There is also a considerable amount of control of streams by the strike of the rocks and by faulting, in spite of the generally great depth of soil. In a country where surface exposures of hard rocks are so very sparse, the total of information obtained is large, and would represent a sensible amelioration of the task of the geologist charged with mapping the area.

In conjunction with the remarks of Mr. Bourne, it would seem reasonable to conclude that Dr. Hawkes believes that ecological indications may be followed by the geologist in Northern Rhodesia when they give rise to sweeping bands not in conflict with other data at hand: the jig-saw puzzle effect produced by the purely vegetational map would appear to be due principally to the interference of man in the past.

My own reading of Mr. Bourne's published work on this area (bibliography 91) is to the effect that ecological boundaries indicate geological changes *when they are considered in relation to the other evidence available*, and that an ecological boundary taken by itself may have no geological significance whatever.

There appears to be no doubt that if and when geological-ecological work is attempted in the future in this or similar country, the geologist and the ecologist must work together in the field and that the interpretation of the photographs must be *systematically* carried out on the ground to which they refer.

I completely agree with Mr. Robert Annan's remarks regarding the help that can be given by vertical photographs, studies stereoscopically, in investigating the structure of ore-deposits, provided the country is suitable. His warning about "limiting observation to what is actually seen" is timely: at

the same time, a person studying photographs must not unduly restrict the free play of his imagination in three dimensions, since the photographs are provided for the purpose of helping him to understand the structure, and adequate ground-control of all inferences made is postulated.

With regard to the form of the photographs, I like contact-prints for the reasons stated in the paper, and for the additional reason that with contact-prints the whole of the overlap is in the field of view at one time. In the Wanderer prints exhibited by Mr. Annan, the amount of enlargement was too great to permit the whole of any overlap to be scanned without moving the prints, and hence part of the advantage conferred by the aerial view was lost.

Mr. Hemming's remarks are valuable, as coming from one who has organised many important aerial surveys. His *questionnaire* for the intending client will prove useful, as well as his remarks on costs. It is to be hoped that nobody has been misled by his "extreme" quotation of £2,500 per square mile; this was the cost of a very detailed city survey, in which the amount of detail mapped was so great that the individual steps of flights of front-doorsteps were shown.

Professor Illing, while a firm believer in the preliminary reconnaissance from the air, does not appear to have any great faith in the use of vertical photographs, since he emphasises that "the essential evidence is obtained only by covering the ground on foot." I quite agree that this is the case and must always be the case, but I believe that in many instances the use of vertical photographs can greatly reduce the labour involved in getting essential evidence on the ground and in many instances can increase the precision of the work on the ground.

Incidentally, the example which he gives is interesting from the point of view of cost; he did from the air (by visual reconnaissance aided by some photographs) in three hours what he had failed to do on foot in two months—that is, to get a general idea of the country (near Maracaibo) and trace a certain sandstone-bed. His trip in the air probably cost not more than from £20 to £30, while his abortive expedition on the ground, if all camp and living expenses are included, may have cost from fifteen to twenty times as much.

I am obliged to Dr. Coggin Brown for his bibliographical note, which is also a historical note of interest. It would be interesting to know whether Sir Edwin Pascoe had heard of the work of Colonel A. H. Brooks when he did this work in Mesopotamia, or whether the idea of using the aeroplane for geology came to him independently.

Thanks are due to Brigadier Winterbotham for his careful contribution, containing numerous references to the "Manual of Map Reading." I can confirm the utility of the pseudo-stereoscopic effect in the circumstances he mentions.

With regard to terminology, the Americans seem still to use the word "aerial" (see titles in bibliography, for example). I do not like the word now, since I find everybody speaks of "aerial geology" as though it were spelt "areal geology," a term with a definite meaning entirely different from that which I wish to convey with "aerial geology." Possibly someone could suggest a better term to fill the bill. I may say that I dislike Mr. Hobson's "geo-aerial surveying" even more than my own term.

Mr. Hatton has serious doubts about the possibility of contouring from aerial photographs. They would be set at rest by a perusal of the works of Captain Hotine, listed in the bibliography (section 1), or of the recent paper by Lieut. Salt, listed at the end of this reply. Aerial survey (or air-survey) is a youthful art, and the errors of "hundreds of feet" in elevation quoted by Mr. Hatton would not occur on recent air-survey maps; the example quoted by Mr. Hatton must refer to early work. It may be mentioned that in contouring from photographs about four spot-levels are required per square mile as a control; these may be instrumentally or barometrically determined, depending upon circumstances.

With regard to the quality of pictures, I do not consider that the interpretation of geology from the air could be helped by the use of colour-photography; indeed, it would be impossible to take vertical photographs in true colours owing to the necessity of filtering out the blue end of the spectrum to counteract haze. I do think, however, that further experiment is required in the direction of using heavier and heavier filters in conjunction with specially red-sensitive and even infra-red-sensitive films. Such combinations would, I think, tend to emphasise slight differences in the colours of soils and outcrops as seen by the aero camera. *The Times* is doing work on these lines in conjunction with the Air Survey Co., and they published some oblique air-photographs recently, taken with the Ilford infra-red film and filter. Apparently they have not yet succeeded in reducing the exposure sufficiently to allow of vertical photographs being taken in the infra-red.

I take it that Mr. Hatton's reference to " Ophir " is a reminder to me that I neglected to mention *old workings* as useful indications of mineralisation that could be spotted from the air. The omission was inadvertent. It has also been referred to by Mr. Annan and Mr. Hobson in the course of this discussion.

I am much obliged to Dr. Wade for his bibliographical reference, which I regret is inaccessible to me where I now am. Extracts from Zuber's bibliography are being made for me.

I am in complete agreement that skilful use must be made of shadows, but not with the implication that all flights should necessarily be made when the sun is low (if such implication was intended). Hilly country with steep slopes may necessitate photography as near midday as possible, in order to avoid shadows that are too black.

The difference of opinion between myself and Dr. Wade on the subject of the use of the stereoscope is, I think, largely a matter of difference of outlook and scale. The oil-geologist in the early stages of an examination will demand visual reconnaissance from the air, with a few photographs to act as his memory, while the man primarily interested in ore-deposits will prefer the stereoscopic examination of vertical photographs, which may give him hints towards the better understanding of the rather intimate structural geology of a limited area. The oil-geologists, using air survey in California (where over 25,000 square miles of oil lands have been photographed from the air), appear to have standardised on the use of the stereoscope.

Mr. J. H. Goodchild's contribution is written from the heart, but I am not entirely certain that I catch the drift of it. So far as the last two paragraphs are concerned, I am not personally familiar with the South of Spain, but from what I can gather, it would be favourable country for a study on the lines indicated by Mr. Annan and myself. I am sure that I wish Mr. Goodchild good hunting in his search for an air-survey organisation willing to do a big survey for nothing.

Mr. Hobson's notes upon what he thinks he could see from the air in Burma are of the greatest interest. Such notes, together with records of actual achievements in the direction of making geological inferences from the air, are what is wanted to complete the edifice of which the paper is merely the foundation. It is to be hoped that mining companies which have used air-survey will permit their mining geologists to publish accounts of the results obtained. The present economic situation is such that any addition to what Professor Boswell calls the " armoury geologic " should receive the widest publicity if it can in any way aid in increasing the production of gold. If air survey applied to geology can be of the least help in this direction, as I believe it can, then the paper will have justified its publication.

The further communications asked for by Mr. Annan, who would like a summary, and by Mr. Hatton, who wants to know more about aerial geology in relation to ore-deposits, may, I think, best be deferred for the time being.

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AN ECHO OF THE 1868 EXHIBITION

BY

W. O. MANNING, F.R.Ae.S.

An occasional glance into the past is often of interest. The following notes refer to an event which was one of the principal landmarks in the history of aeronautics, and which attracted much interest abroad, especially in France. It is hardly necessary to remind the reader that the Aeronautical Society of Great Britain subsequently referred to, is now the Royal Aeronautical Society.

The year 1868 was a year of mark in aeronautics, for it was then that the Aeronautical Society of Great Britain held the first Aero Exhibition in the Crystal Palace. There was being published in France at that time an aeronautical journal called "L'Aeronaute," to which Docteur Abel Hureau de Villeneuve was a frequent contributor, and his remarks on current events, both in England and France, are of considerable interest. He was certainly a keen observer and a most intelligent man.

In April, 1868, he contributed an article on the subject of this exhibition in which he discusses the advantages to his compatriots of exhibiting there. He recommended that those firms who manufacture materials likely to be used in aeronautics should make a point of doing so, and adds a list of materials which they might hope to sell—a list not without interest. One notes silk and cotton among the fabrics, cane bamboo, spruce, and hard woods for pulleys among the timbers; steel, and surprisingly, aluminium and its alloys among the metals. There are also varnishes and oils. Among miscellaneous items one notices propellers, rudders, inclined planes, barometers, anemometers, compasses and appliances for producing light and heat without danger of fire.

He also encourages the French inventor to exhibit principally for the rather curious reason that he might be able to interest an English capitalist in his schemes, though he notes that the successful flying machine is not likely to be the result of the work of one man, but will require much science, much organisation and much capital. Dr. Villeneuve was officially accredited to this exhibition by the French scientific societies.

It seems that there was a certain optimism at that time, for the Duke of Sutherland offered a prize of £100 to the inventor of a machine which, being neither a kite nor a balloon, would lift a man to a height of 120ft. There was also a prize of £50 offered by the Aeronautical Society to the exhibitor of the lightest engine in proportion to its horse-power. This prize was eventually won by Mr. Stringfellow. Dr. Villeneuve praises highly the sagacity of the Society in offering these prizes, laying stress on the fact that practical results must wait for the production of light motors. It seems that, as has happened in later times, every inventor who exhibited a machine believed that he had solved the problem of aerial locomotion, but Dr. Villeneuve notes that the public did not believe them, and that he did not believe them himself, though he fears that this statement will annoy the inventors.

Later, he notes, without believing them, certain rumours which were current in London about that time. It seems that certain English papers announced that a M. Kauffmann had constructed a machine with a 50-h.p. steam engine which

was shortly expected to fly, and that a Mr. Spencer had flown 250ft. at, apparently, a height of 25ft. He went to see Mr. Spencer, who, it seems, suspended himself from the ceiling with a vertical cord, having attached to his back a tail 12ft. long. Thus arrayed and suspended he proceeded to move his arms and his tail with great energy. M. Villeneuve notes calmly that his efforts were not crowned with success. The Kauffmann apparatus was, apparently, a small steam-driven model which would not even be made to move its wings, in spite of ample supplies of steam supplied from an outside boiler. In fact, the only apparatus which could do anything was that of Mr. Stringfellow, which ran up and down a horizontal wire, driven by a steam engine.

In a later number he talks about light motors and comments on the fascination the steam engine had then for the inhabitants of England and America. It seems that small boys got toy steam engines to play with instead of toy guns, and that every undergraduate had a model boat, driven by steam, four or six feet long. But he says he has not been able to find a light steam engine of any value in England.

He notes that, in France, experiments were being made with motors driven by solid or liquid carbonic acid gas and also by liquefied ammonia, but does not believe in electric propulsion of aircraft as being much too heavy. He then suggests that the future is with a motor which will use directly the increase of pressure generated by the heating of air in a closed space by burning oil in it, and allows the heated gas resulting to act directly on a piston. This successful prophecy was, perhaps, the result of examining a Lenoir gas engine.

He discusses the question of fuel for such an engine constructed for aerial navigation, but notes that at the present stage it doesn't really matter whether the engine consumes alcohol, ether, diamonds or attar of roses, the important thing being to fly somehow, as economy can come later.

Motors using gun cotton seem to have been popular then amongst inventors, though gunpowder had some adherents. M. de Villeneuve discusses them in detail and refers to the deposits left by gunpowder as likely to interfere with the working of the motor. It is not clear that motors operated by these two explosives were ever made to run, which was, probably, fortunate for the inventor.

It seems that the inventor who wished to sell a secret invention without disclosing it, is not a modern development. Dr. Villeneuve seems to have met a number, one of whom wanted as much as £6,000 for his invention, but he was not to be tempted in this way.

He discourses further on the subject of motors, and notes that one should be able to burn air carburated with some mineral spirit in a gas engine—presumably a Lenoir—but considers that electrical ignition would not be satisfactory. He thinks some form of rotary engine would be better than using pistons, connecting rods and crankshaft, on account of the weight of the latter, and is worried about the necessity for a flywheel. He thinks of replacing the latter by a spring arranged to pull the engine over the dead centres.

He next discusses the materials out of which light engines might be made. Cast iron, wrought iron, copper, brass, gunmetal, aluminium bronze, and various sorts of steel are among those mentioned. This early mention of aluminium bronze is interesting, but the metal was not, apparently, satisfactory as it crumbled when hammered. He states the breaking load and the specific gravity of these materials, and considers that aluminium is not a suitable material to make boilers out of. The price of this metal was then about £2 10s. per pound.

He considers Stringfellow's steam engine as not presenting any novelty, but as being very carefully constructed, and believes that a 4-h.p. steam engine could be made for 22lbs. weight.

He publishes the report of the Aeronautical Society of Great Britain which gave the Society's prize to Stringfellow, whose steam engine was stated to give a little more than one horse-power for a weight of 13lbs. complete.

The method of calculating the horse-power of this engine was apparently carried out as follows:—

Data.—Area of piston 3 sq. in.
Pressure in cylinder, 80lbs. sq. in. (This figure seems to have been estimated. Boiler pressure was 100lbs.)
Revolutions per minute, 300.
Stroke of piston, 3 ins.
Speed of piston, 150 ft. per minute.
Hence power output equalled $3 \times 80 \times 150 = 36{,}000$ ft. lbs. per minute.

Dr. Villeneuve approves of this award, but considers himself somewhat unfortunate. It seems that he had under his charge a steam engine made by a compatriot, the Viscount de Ponton a Amercourt, which he considered had a good chance for the prize. This apparatus was constructed in aluminium and was intended to work at a pressure of 150lbs. per sq. in. Unfortunately someone had forgotten to bring the pressure gauge, and as no suitable one was to be obtained in London it was considered dangerous to operate such a high pressure machine without knowing the pressure.

Dr. Villeneuve's Secretary, M. Smitter, who was also present in London, offered to take the risk and run the engine. This, however, Dr. Villeneuve would not allow. While he considered that his Secretary was perfectly free to risk his own life if he wanted to, yet he could not agree to a valuable piece of apparatus being run under conditions which might lead to it being damaged. So the prize was won by Stringfellow without opposition.

THE ROYAL AERONAUTICAL SOCIETY

With which is incorporated The Institution of Aeronautical Engineers

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SIXTY-EIGHTH ANNUAL REPORT OF THE COUNCIL, 1932—33

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Advisory Council of the Science Museum: Colonel the Master of Sempill.

National Central Library: Mr. J. E. Hodgson.

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Association of Special Libraries and Information Bureau: Mr. J. E. Hodgson (Hon. Librarian).

Advisory Committee on Aeronautical Education of the Imperial College: Mr. C. R. Fairey.

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Seagrave Memorial Fund Committees: Mr. C. R. Fairey.

British Gliding Association: Council: Colonel the Master of Sempill. Technical Committee: Capt. J. L. Pritchard, Capt. F. T. Hill.

Membership

In the last report attention was drawn to the fact that an Education and Examinations Committee of the Council had put forward proposals for the revision of the Society's examinations and the exemptions from them. The reports of the Committee were passed by the Council and certain new rules which were necessary following that report were submitted to the members at the Annual General Meeting and passed. These rules are now in force. The examination standard has now been raised to such a standard that technical membership of the Society is, practically speaking, an almost necessary qualification in the profession of aeronautics. It is the definite aim of the Council that every technical member shall be fully qualified in aeronautical science or engineering in the grade to which he is elected.

The following table shows the membership for the past year and the previous one. The table reveals the fact that the membership of the main body has decreased slightly during the year. The year 1932 has been a most difficult one, and in view of the fact that the membership of many societies has heavily declined, the result is satisfactory and in itself is symptomatic of the high standing of the Society.

	No. of Members.		Hon. & Life Members.		Suspended.		Total.	
Fellows	135	(110)	20	(20)	4	(—)	159	(130)
Members	56	(55)	—		3	(3)	59	(58)
Assoc. Fellows ...	413	(437)	5	(5)	16	(13)	434	(445)
Assoc. Members ...	88	(104)	—		9	(5)	97	(109)
Associates	166	(162)	3	(3)	15	(10)	184	(175)
Companions	98	(107)	11	(13)	3	(3)	109	(123)
Founder Members ...	25	(31)	1	(—)	2	(1)	28	(32)
Students	271	(271)	—		27	(10)	298	(281)
Temp. Hon. Members	—		18	(25)	—		18	(25)
	1252	(1277)	57	(66)	76	(35)	1366	(1378)
Less Joint Members ...	28	(29)						
	1224	(1249)	57	(66)	76	(35)	1366	(1378)

Donations

The Council have again to thank the Air Ministry and the Society of British Aircraft Constructors for their generous donations of £250 to the funds of the Society, and the Society of Motor Manufacturers and Traders for a donation of £100. The donation from the Air Ministry has now been given for eight years in succession, and that for the Society of British Aircraft Constructors also for the eighth year in succession. The grants which have been made to the Society have been invaluable, and it is indeed largely due to the help given by the Air Ministry, the Society of British Aircraft Constructors, the Society of Motor Manufacturers and Traders, and the Guggenheim Trust Fund, which have enabled the Society to reach its present position.

Endowment Fund

The table below shows the progress of the Endowment Fund:—

	£	s.	d.
December, 1926	575	0	0
December, 1927	597	2	0
December, 1928	1,047	18	0
December, 1929	1,077	6	0
December, 1930	1,265	10	0
December, 1931	1,935	10	1
December, 1932	2,196	2	0

The increase of the Fund in 1932 is due largely to the amount received from Entrance Fees, which are now added regularly to the Fund. The year 1932 was even a more difficult year financially than 1931. The policy of the Council is to increase the Fund in every possible way in order that the Society shall be in an unassailable position financially in the future and be independent of fluctuations in industry. There is every hope that the Fund will be increased substantially with a world change in the economic situation. The Council urge every member to bear constantly in mind the very real importance of the Fund and the benefit it will bring to all members.

Library

For the ninth year in succession the Council have to thank Mr. J. E. Hodgson, the Honorary Librarian, for the time he has given to the Library and for the able advice which he has regularly given with regard to the books and acquisition of historical material. The Council have also to thank him for acting as their representative at the Council meetings of the National Central Library for Students and the Association of Special Libraries and Information Bureaux.

During the year many slides, photographs and books were acquired or presented to the Library by members and firms, acknowledgments of which were made in the Annual Summary of the Society's activities in the Journal for December, 1932. The Society's collection of aeronautical slides is one of the finest in existence and is being added to steadily. During the year an index of these slides was published.

The Council again urgently suggest to all members who have slides or photographs or other aeronautical items of interest which they find any difficulty in storing, to look upon the Society as a suitable repository by letting the Society have them on permanent loan. They will be readily available for the member when he wishes to use them, and he will be rendering invaluable service by making them available to other members. This appeal particularly applies to slides and photographs, the requests for which have increased greatly during the past twelve months.

The Technical Index which was begun a few years ago has become increasingly useful each year, and is now a most valuable aid to members, who are constantly consulting it. The object of the Council, to induce anyone who wishes to obtain any information about aviation to apply in the first place to the Society, is rapidly being achieved.

The experiment of opening the Library on Saturday afternoons has proved a success. The Library is closed on periodical Wednesday afternoons for the meeting of the Council of the Society of British Aircraft Constructors, who have paid all the expenses of keeping the Library open on Saturday afternoons.

The increasing demand for room for storing historical papers, documents, photographs and slides is making the problem of reorganising the Library one of some urgency. The Library has been reshelved during the year and a considerable amount of formerly waste space has been made use of.

Wilbur Wright Memorial Lecture

The Wilbur Wright Memorial Lecture for 1932 was delivered before a distinguished audience on Thursday, May 26th, 1932, by Mr. H. E. Wimperis, C.B.E., F.R.Ae.S., Vice-President, on "New Methods of Research in Aeronautics," in the Aeronautical Section of the Science Museum, South Kensington, S.W.7. The lecture was preceded by a Council Dinner and followed by a reception and conversazione. A full report appeared in the December, 1932, issue of the Journal.

Lecture Prorgamme

A full list of lectures delivered before the Society, and the principal lectures delivered before the Branches, was given in the Journal for December, 1932. In addition, the following lectures have been delivered or arranged for during the remainder of the present session:—

January 12th.—"Airship Development Abroad." Squadron Leader R. S. Booth, A.F.C., R.A.F.

January 26th.—"Human Limits in Flying." Wing Commander G. S. Marshall, O.B.E., M.R.C.S., L.R.C.P.

February 2nd.—"The Operation of Aircraft over Tropical Routes." Mr. A. Plesman.

February 16th.—"Cloud Formation." Sir Gilbert T. Walker, C.S.I., F.R.A.S., F.R.S.

February 22nd.—Nat. Air Races Film. R. L. Preston, Esq., A.F.R.Ae.S.

March 7th.—"Some Notes and Observations on Petrol and Diesel Engines." H. R. Ricardo, Esq., B.A., F.R.S., F.R.Ae.S. (Joint Meeting with I.A.E. Roy. Geog. Soc. 7.30 p.m.)

March 9th.—"Engine Cooling Research." R. McKinnon Wood, Esq., O.B.E., M.A., A.M.Inst.C.E., F.R.Ae.S.

March 16th.—"The Work of the Central Aerodynamic Institute, Moscow." Professor A. Toupoleff. (Inst. of Civil Engineers, 6.30 p.m.)

April 6th.—"Lessons of the Do.X." Dr. C. Dornier. (Inst. of Civil Engineers, 6.30 p.m.)

April 27th.—"Seaplane Research." H. M. Garner, Esq., M.A., F.R.Ae.S.

Lectures before the Branches

January 19th (Yeovil Branch).—"American Aviation Progress." Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., F.R.Ae.S.

January 20th (Manchester Branch).—"The Conquest of Soaring Flight." Captain C. H. Latimer Needham, M.Sc., F.R.Ae.S.

February 16th (Yeovil Branch).—"Aero Engine Development." Major G. P. Bulman, O.B.E., F.R.Ae.S.

February 24th (Gloucester and Cheltenham Branch).—" The Conquest of Soaring Flight." Captain C. H. Latimer Needham, M.Sc., F.R.Ae.S.
March 2nd (Yeovil Branch).—" Aircraft Armament Installations, etc." Squadron Leader C. Crawford, R.A.F.
March 16th (Yeovil Branch).—" Petter Oil Engines." Mr. Sammons, of Petters Ltd.
March 29th (Yeovil Branch).—" Airflow." W. S. Farren, Esq., M.B.E., F.R.Ae.S., M.I.Ae.E.

Students' Section

The Students' Section during 1932 again continued to show a very satisfactory increase both in activity and membership. Many of the students are now being recruited from the Royal Air Force, and the Council again wish to thank all those officers who have taken a long view of the future careers of the men under them and encouraged them to become students and ultimately to prepare for the Society's examinations or those Royal Air Force examinations which exempt from those of the Society.

The Council wish to impress upon all students the importance of taking every opportunity for increasing their knowledge with the object of becoming technical members of the Society and so increasing their prospects. Technical membership of the Society is of definite value when applying for an appointment.

In November, 1932, Mr. C. H. Jackson was appointed Secretary of the Students' Section, and a new Committee was appointed. New rules for the Section were agreed upon at the Annual General Meeting of the Students' Section. These rules were published in the December Journal (1932).

In addition to the lectures announced in the December, 1932, Journal, the following have been given, or arranged for, before the Students' Section:—

December 20th, 1932.—" Slots." Mr. B. Cornthwaite.
January 10th, 1933.—" Some Notes on the High Pressure Pipe Effects on Fuel Injection." C. W. Lawson.
January 31st.—" Detonation." F. R. B. King.
March 7th.—" Duralumin applied to Aircraft Construction." W. H. Lewis, B.Sc., A.C.G.I.
May 16th.—" Aircraft Instruments." D. Hay Surgeoner.

Visits

December 10th, 1932.—The H. G. Hawker Engineering Company.
February 18th, 1933.—The Fairey Aviation Company.
March 18th.—Messrs. Short Bros. (Rochester and Bedford), Ltd.
May 6th.—The Royal Aircraft Establishment, South Farnborough, Aerodynamics Section.
May 27th.—The Royal Aircraft Establishment, South Farnborough, Motor Testing Section.

Public Schools' Lectures

The experiment of delivering lectures before the Public Schools which was inaugurated in 1931-32 proved so successful that it has been repeated this year, and there has been a constant and increasing demand for further outside lectures and for slides from members for lecture purposes to local organisations. Since the lectures started some 200 have been arranged for, and lectures have been delivered before audiences totalling some 40,000.

Many members of the Society at once signified their willingness to spare the time to deliver a lecture before a school, and some members have delivered a number of these lectures. The Council wish to record their thanks to all those who have helped in this way in a work which they consider of primary importance.

The Council would be glad to hear from any member who would be willing to lecture before a school in his neighbourhood. They feel it is of great importance that the opportunity of rousing interest in the air among those who are bound to have a great influence during the next few years should be seized upon.

In addition to the list published in the December Journal, the following have been arranged for, or delivered, in 1933:—

January 5th.—Hull Aero Club. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

January 11th and 13th.—Lectures at Armstrong College, Newcastle-upon-Tyne, for "young persons" on "Flight." E. G. Richardson, Esq., D.Sc., Ph.D., Comp.R.Ae.S.I.

January 24th.—Ealing Central Boys' School. J. T. Morton, Esq., A.F.R.Ae.S.

January 25th.—Manningtree School. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.

January 26th.—King's School, Chester. Flight Lieut. N. Comper, A.F.R.Ae.S.

January 30th.—Nottingham High School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 1st.—St. Andrew's Guild, Upper Norwood. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 3rd.—Royal Grammar School, High Wycombe. Major D. H. Kennedy, O.B.E., F.R.Ae.S.

February 3rd.—Upton College. J. T. Morton, Esq., A.F.R.Ae.S.

February 4th.—Rugby School. Lieut.-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.

February 4th.— Highgate School. W. O. Manning, Esq., F.R.Ae.S.

February 4th.—Mill Hill School. Capt. A. G. Lamplugh, A.C.G.I., F.R.Ae.S., M.I.Ae.E.

February 4th.—Salford Technical Institute. T. Hampson, Esq., Secretary, Manchester Branch, R.Ae.S.I.

February 6th.—Birkenhead School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 7th.— Blackpool Secondary School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 7th.— Durham School. E. G. Richardson, Esq., D.Sc., Ph.D., Comp.R.Ae.S.I.

February 10th.—Willaston School, Cheshire. Flight Lieut. N. Comper, A.F.R.Ae.S.

February 11th.—Reading School, Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.

February 17th.—St. Lawrence College, Ramsgate. Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I.

February 18th.—Christ's Hospital. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.

February 18th.—King's School, Worcester. F. Radcliffe, Esq., B.Sc., A.R.Ae.S.I.

February 20th.—Redhill Conservative Association. A. P. Thurston, Esq., M.B.E., D.Sc., F.R.Ae.S.

February 22nd.—Bristol Grammar School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 23rd.—Denstone College. Capt. J. Laurence Pritchard.

February 23rd.—Exeter School. J. E. G. Labey, Esq., A.F.R.Ae.S.

February 25th.—Charterhouse. C. R. Fairey, Esq., M.B.E., F.R.Ae.S. (President).

February 25th.—Eastbourne College. S. Scott-Hall, Esq., M.Sc., D.I.C., A.F.R.Ae.S.

February 28th.—Liverpool College. Flight Lieut. N. Comper, A.F.R.Ae.S.
March 7th.—Haberdasher Aske's Hampstead School. J. H. Edge, Esq., Comp.R.Ae.S.I.
March 8th.—Wrekin College. Major T. M. Barlow, M.Sc., F.R.Ae.S.
March 8th.—Bromsgrove School. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
March 11th.—Ipswich Scientific Society. S. Scott-Hall, Esq., M.Sc., D.I.C., A.F.R.Ae.S.
March 16th.—Liverpool University. Squadron Leader R. V. Goddard, R.A.F.
March 17th.—Epsom College. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.
March 22nd.—Liverpool Engineering Society. Flight Lieut. N. Comper, A.F.R.Ae.S.

Branches

The year 1932 has been a very difficult one for the Branches. The general financial situation and uncertainty has resulted in a general falling off of membership, but the activities of the Branches have not lessened. The Council feel, indeed, that the Chairmen, Committees, and Secretaries of the various Branches have done work of the utmost value during the year in arranging lectures and keeping up an interest in aviation at a period when great difficulties have had to be encountered and overcome. The list of lectures read before the Branches is an imposing one, and is in itself an eloquent testimony of the energy and enthusiasm of all those connected with the Branches. The Council urge upon everyone to support their Branches to the fullest possible extent, especially during periods of stress.

The newly formed Branches at Ottawa and Montreal are a source of great gratification to the Council. The papers read before these branches are printed in a special supplement of the Engineering Journal of Canada, and circulated from time to time with the Journal to all members. From opinions which have been received, these papers have proved of very great value and constitute a strong link between Canadian and British Aviation. The first of the Dominion Branches to be formed was in Australia, and this Branch, despite the great difficulties of organisation, is flourishing strongly under the able Secretaryship of Mr. J. V. Connolly, Associate Fellow.

The following is a list of Branches and their addresses:—

Bristol.—Hon. Secretary: C. W. Tinson, Esq., F.R.Ae.S., Beaufort House, Southmead Road, Filton, Bristol.

Coventry.—Hon. Secretary: F. Meadows, Esq., A.F.R.Ae.S., "Llangstone," Jobs Lane, Coventry.

Gloucester and Cheltenham.—Hon. Secretary: L. W. Nethercott, Esq., A.R.Ae.S.I., "Bearswood," Glencairn Park Road, Cheltenham.

Hull and Leeds.—Hon. Secretary: G. B. Fenton, Esq., A.F.R.Ae.S., 37, Lonsdale Street, Anlaby Road, Hull.

Manchester.—Hon. Secretary: T. Hampson, Esq., A.R.Ae.S.I., 57, Westbourne Road, Monton, Eccles, Manchester.

Yeovil.—Hon. Secretary: V. S. Gaunt, Esq., A.M.I.Ae.E., Westland Aircraft Works, Yeovil.

Australia.—Hon. Secretary: J. V. Connolly, Esq., A.F.R.Ae.S., Science House, Gloucester and Essex Streets, Sydney, Australia.

Montreal Aeronautical Section.—2050 Mansfield Street, Montreal.

Ottawa Aeronautical Section.—Hon. Secretary: Squadron Leader A. Ferrier, A.F.R.Ae.S., Dept. of National Defence, Slater Street, Ottawa, Canada.

Cambridge University Aeronautical Society (Affiliated).—Hon. Secretary: Mr. Hancock, Scoope House, Cambridge.

President

At the meeting of Council held on June 22nd, 1932, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was unanimously elected President for a third year of office, October, 1932—September, 1933.

It will be remembered that the rule which allowed the President to be elected for not more than two years of office was suspended at a special meeting held on June 9th, 1932, in order that the Society should have the benefit of Mr. Fairey's experience for a further term of office.

Mr. Fairey's terms as President have coincided with one of the most severe financial depressions ever experienced. Mr. Fairey, however, has proved a tower of strength to the Society financially and otherwise. Thanks to his own personal efforts, the Endowment Fund was increased during his first year of office by over £600—the greatest increase in any one year since the fund was started. In many other ways, during his period of office, Mr. Fairey has personally paid considerable sums which the Society would otherwise have to meet, notably the heavy deficit on the Wilbur Wright Memorial Lectures and Conversaziones and the entertainment of lecturers from abroad. The Council wish to express their grateful thanks and deep appreciation of the time, energy and financial assistance which the President has given to the Society, all of which are reflected in the increasing prestige and sound financial position of the Society at the present time.

Journal

The growth and influence of the Journal have continued during 1932, the revenue from outside sales keeping up with 1931 despite the general depression. Over £1,300 was actually received from outside sales of the Journal. The amount in the Income and Expenditure Account of £824 for Journals and Pamphlets (less sales) represents in the main the cost of distributing the Journal free to all members. There is every sign that the demand for Journals throughout the world is steadily increasing, and the Council confidently look forward to the time when these sales will be large enough to pay for the total cost of sending the Journal to members. The circulation of the Journal in the last five years has nearly doubled, and the demand for it from abroad has increased in a proportionate amount. It is undoubtedly the foremost technical aviation journal published.

A new advertisement contract has been entered into which will enable the Society to obtain greater and more direct benefit from the advertisement pages in the future. The new contract has enabled the Journal to be altered in a number of ways, notably the removal of the advertisement from the front page of the cover.

Finance

The Balance Sheets and Income and Expenditure Accounts of Aerial Science, Ltd., and of Aeronautical Trusts, Ltd., are published in this issue of the Journal. The form in which the accounts are drawn up shows an excess of income over expenditure of £290 9s. 3d. This excess is entirely due to the donations which have been received. Deducting these donations, which are year by year grants and cannot be looked upon as permanent, there is an actual loss on the year of £115 8s. 5d. The actual losses (without donations) in previous years were as follows:—

	£	s.	d.
1931	159	12	11
1930	186	14	2
1929	862	0	0
1928	600	0	0

(Continued on page 306).

AERONAUTICAL

Balance Sheet,

	£ s. d.	£ s. d.	£ s. d.
Share Capital—			
Authorised—			
40 Shares of 1/- each		2 0 0	
Issued—			
21 Shares of 1/- each		1 1 0	
Less—Calls in arrear		1 1 0	
Pilcher Memorial Fund—			
Capital Account—			
As at 31st December, 1931.		99 14 0	
Income Account—			
Balance as at 31st December, 1931	26 4 0		
Add Surplus of Income over Expenditure for year to date	1 18 4	28 2 4	
			127 16 4
Usborne Memorial Fund—			
Capital Account—			
As at 31st December, 1931		109 2 5	
Income Account—			
Balance as at 31st December, 1931	18 18 5		
Add Surplus of Income over Expenditure for year to date	6 15 7	25 14 0	
			134 16 5
Herbert Akroyd Stuart Fund—			
Capital Account—			
As at 31st December, 1931		688 19 0	
Income Account—			
Balance as at 31st December, 1931	68 8 0		
Add Surplus of Income over Expenditure for year to date	40 19 7	109 7 7	
			798 6 7
R.38 Memorial Fund—			
Capital Account—			
As at 31st December, 1931		978 3 10	
Income Account—			
Balance as at 31st December, 1931	212 3 4		
Add Surplus of Income over Expenditure for year to date	36 13 2	248 16 6	
			1227 0 4
Edward Busk Memorial Lecture Fund—			
Capital Account—			
As at 31st December, 1931		449 6 1	
Income Account—			
Balance as at 31st December, 1931	70 10 9		
Add Surplus of Income over Expenditure for year to date	3 5 7	73 16 4	
			523 2 5
Wilbur Wright Memorial Fund—			
Capital Account—			
As at 31st December, 1931		1298 9 9	
Income Account—			
Balance as at 31st December, 1931	85 12 11		
Add Surplus of Income over Expenditure for year to date	2 17 6	88 10 5	
			1387 0 2
Simms Gold Medal Fund—			
Capital Account—			
As at 31st December, 1931		250 0 0	
Less—Income Account Deficiency as at 31st December, 1931	8 15 2		
Add Excess of Expenditure over Income for year to date	5 8 4	14 3 6	
			235 16 6
			£4433 13 9

We report to the Members of Aeronautical Trusts, Ltd., that we have examined the above Balance Sheet is properly drawn up explanations we have required. We are of opinion that the December, 1932, according to the best of our information and the explanations given to us and as

8, Frederick's Place, Old Jewry, London, E.C.2.
15th February, 1933.

TRUSTS, LTD.

31st December, 1932.

	£ s. d.	£ s. d.
Pilcher Memorial Fund—		
£115 6s. 10d. 3½ % War Loan at cost	116 5 0	
Cash at Bank	16 11 4	
	132 16 4	
Less—Amount owing for 1932 Award	5 0 0	
		127 16 4
Usborne Memorial Fund—		
£113 3½ % War Loan at cost	114 11 1	
Cash at Bank	20 5 4	
		134 16 5
Herbert Akroyd Stuart Fund—		
£683 1s. 0d. 3½ % War Loan at cost	698 19 0	
Cash at Bank	99 7 7	
		798 6 7
R.38 Memorial Fund—		
£1048 11s. 2d. 3½ % War Loan at cost	1098 18 10	
Cash at Bank	154 6 6	
	1253 5 4	
Less—Amount owing for 1932 Award	26 5 0	
		1227 0 4
Edward Busk Memorial Fund—		
£284 4s. 2d. 3½ % War Loan at cost	284 4 2	
£245 Metropolitan Railway 4 % Debentures at cost	200 1 11	
	484 6 1	
Cash at Bank	59 16 4	
	544 2 5	
Less—Amount owing for 1932 Award	21 0 0	
		523 2 5
Wilbur Wright Memorial Fund—		
£1047 6s. 7d. 3½ % Conversion Stock, at cost	800 0 0	
£550 Canadian 4 % Stock, at cost	531 10 9	
	1331 10 9	
Cash at Bank	88 10 5	
	1420 1 2	
Less—Amount owing to Aerial Science, Ltd.	33 1 0	
		1387 0 2
Simms Gold Medal Fund—		
£287 16s. 1d. India 4½ % Stock, 1958/68, at cost	250 0 0	
Cash at Bank	19 6 6	
	269 6 6	
Less—Amount owing to Aerial Science, Ltd. 16 15 0		
Amount owing for 1932 Award ... 16 15 0	33 10 0	
		235 16 6
		£4433 18 9

Balance Sheet with the books of the Company and have obtained all the information and so as to exhibit a true and correct view of the state of the Company's affairs as at 31st shown by the books of the Company.

PRICE, WATERHOUSE & CO.

AERIAL SCIENCE, LIMITED

Balance Sheet,

	£ s. d.	£ s. d.
Share Capital—		
Authorised—		
20 Shares of 1/- each	1 0 0	
999 Shares of £1 each	999 0 0	
	1000 0 0	
Issued—		
19 Shares of 1/- each, fully paid		0 19 0
Sundry Creditors		474 11 5
Bank Overdraft		268 14 11
Amount owing to Endowment Fund—as per contra		261 0 11
Subscriptions Received in Advance		172 3 1
Carnegie U.K. Trust Grant for Purchase of Books—unexpended balance		34 11 5
Endowment Fund—		
Balance at 31st December, 1931	1935 10 1	
Add—Donations received during year	27 6 6	
Entrance Fees received during year	166 13 0	
Bonus and Commission on Conversion of War Loan	66 12 5	
		2196 2 0
Surplus—		
Reserve Fund	3553 0 9	
Income and Expenditure Account—		
Balance as at 31st December, 1931 ... ... 4807 5 7		
Add—Surplus of Income over Expenditure for the year to date 290 9 3		
	5097 14 10	
		8650 15 7
		£12058 18 4

We report to the Members that we have examined the above Balance Sheet with the Books are of opinion that such Balance Sheet is properly drawn up so as to exhibit a true and correct information and the explanations given to us and as shown by the Books of the Society.

3, Frederick's Place, Old Jewry, London, E.C.2.
15th February, 1933.

Income and Expenditure Account

Dr.	£ s. d.
To Office Rent, Heating, Lighting and Insurance	558 3 3
,, Salaries	1213 8 4
,, Printing and Stationery	368 16 11
,, Postages, &c....	162 4 8
,, Office Expenses	191 6 5
,, Meetings	155 12 10
,, Journals, and Pamphlets (*Less* Sales)	824 5 7
,, Library Expenses	45 5 3
,, Audit Fee	29 8 0
,, Prizes and Donations	22 11 0
,, Dinners and Receptions	11 11 3
,, Subscriptions Written off	117 8 0
,, School Lectures	36 4 1
,, Legal Expenses	53 2 6
,, Surplus of Income over Expenditure for Year, carried to Balance Sheet	290 9 3
	£4079 17 4

(The Royal Aeronautical Society).

31st December, 1932.

	£ s. d.	£ s. d.
Office Furniture, Printed Books, Bindings, Old Prints, etc., at cost, as at 31st December, 1931		450 5 11
Stock of JOURNALS *and other Publications*		632 4 8
Stock of Stationery		13 0 0
Sundry Debtors, including Subscriptions owing		209 4 3
Investments at Cost—		
£5552 3s. 0d. 3½% War Loan	5565 4 9	
£1648 3s. 9d. 4½% India Stock, 1958/68	1500 0 0	
£1456 0s. 1d. 4% Treasury Bonds 1934/36	1487 17 4	
(Market value at 31st December, 1932, £8778 10s. 0d.)		8553 2 1
Endowment Fund—		
£2043 19s. 8d. 3½% Conversion Stock	1584 18 3	
£293 18s. 3d. 4% Treasury Bonds 1934 36	295 2 10	
	1880 1 1	
(Market value at 31st December, 1932, £2331 7s. 5d.)		
Cash at Bank	55 0 0	
Amount owing by General Funds, as per contra	261 0 11	
		2196 2 0
Cash in Hand		4 19 5
		£12058 18 4

of the Society, and have obtained all the information and explanations we have required. We view of the state of the Society's affairs as at 31st December, 1932, according to the best of our

(Signed) PRICE, WATERHOUSE & CO.

for the Year Ending 31st December, 1932.

Cr.	£ s. d.	£ s. d.
By Annual Subscriptions		3064 16 11
,, Interest on Investments (Including Endowment Fund Investments) (*Less Tax*)	407 0 1	
,, Income Tax Recovered	158 15 9	
,, Bank Interest	3 9 5	
		569 5 3
,, Donations		405 17 8
,, Sale of Badges (*Less Cost*)		1 15 6
,, Examination Fees *(Less Expenses)*		38 2 0
		£4079 17

AERONAUTICAL

INCOME & EXPENDITURE ACCOUNTS

Pilcher

RECEIPTS.

	£ s. d.
To 1932 Award	5 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	1 18 4
	£6 18 4

Usborne

,, Surplus of Income over Expenditure for year carried to Balance Sheet	6 15 7
	£6 15 7

Herbert Akroyd

,, Surplus of Income over Expenditure for year carried to Balance Sheet	40 19 7
	£40 19 7

R.38

To 1932 Award	26 5 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	36 13 2
	£62 18 2

Edward Busk

To 1932 Award	21 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	3 5 7
	£24 5 7

Wilbur Wright

To 1932 Award	50 0 0
,, Surplus of Income over Expenditure for year carried to Balance Sheet	2 17 6
	£52 17 6

Simms Gold

To 1932 Award	16 15 0
	£16 15 0

TRUSTS, LTD.

FOR THE YEAR ENDED 31ST DECEMBER, 1932.

Memorial Fund

PAYMENTS.

	£ s. d.
By Interest on Investments (gross) including Bonus on Conversion of War Loan ...	6 18 4
	£6 18 4

Memorial Fund

By Interest on Investments (gross) including Bonus on Conversion of War Loan ...	6 15 7
	£6 15 7

Stuart Fund

By Interest on Investments (gross) including Bonus on Conversion of War Loan ...	40 19 7
	£40 19 7

Memorial Fund

By Interest on Investments (gross) including Bonus on Conversion of War Loan ...	62 18 2
	£62 18 2

Memorial Lecture Fund

By Interest on Investments (*less* Tax) including Bonus on Conversion of War Loan ...	24 5 7
	£24 5 7

Memorial Fund

By Interest on Investments (*less* Tax)	52 17 6
	£52 17 6

Medal Fund

By Interest on Investments (*less* Tax)	11 6 8
,, Balance being Excess of Expenditure over Income for year carried to Balance Sheet	5 8 4
	£16 15 0

The loss, it will be seen, is the lowest for five years, a result upon which the Society is to be congratulated, in view of the difficulties of the year.

The annual subscriptions during the year have increased—a most satisfactory sign. During the year the Society's investments were converted to the new $3\frac{1}{2}$ per cent. loans, and this will mean a considerable drop in income from investments in future years, so that continuous effort is required to keep the Society in the position it now is.

The value of stock and the books in the Library has been given at a purposely low figure, and the policy of the Council is year by year to write down the stock until it is shown in the Balance Sheet at a purely nominal figure.

Honorary Solicitor

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I., has continued to act as Honorary Solicitor to the Society, and the Council wish to place on record the valuable services he has rendered. He has advised the Council on a number of important legal questions and has been of considerable help on Committees of Council.

Honorary Treasurer

The Council have had the advantages of the services for the sixth year in succession of Major D. H. Kennedy, F.R.Ae.S., the Honorary Treasurer and Chairman of the Finance Committee. Upon Major Kennedy and the Committee falls the onerous task of conserving the finances of the Society without lessening its activities. Major Kennedy has been fertile in his suggestions for increasing the income of the Society, and the Council wish to place on record the debt which they and all members owe to Major Kennedy for his untiring energy on behalf of the Society, which is so well reflected in the increasingly satisfactory Balance Sheets of the Society during the past few years.

Honorary Accountant

Mr. Norman Smith, the Honorary Accountant, has during 1932 finished his fifth year of office. During that year Mr. Smith has paid special attention to the Income Tax problems, and as a result of his representations to the Commissioners of Inland Revenue the Society's income is now tax free. Through Mr. Smith the Society were able to recover a considerable sum in income tax which had already been paid. The Council wish to record their grateful thanks to him for the time and advice he has so freely given which have resulted in such a lasting benefit to the Society.

Staff

The Staff of the Royal Aeronautical Society is among the smallest staffs of any corresponding Society. During the past six years the office work of the Society has increased very rapidly. It is upon the staff that the real work falls, and upon them that the final efficiency of the administration of the Society depends. The Council wish to record how excellently the work of the Society has been carried out by the Staff—Miss Jarvis, Miss Todd and Miss Voyce, and the Secretary, Captain J. Laurence Pritchard.

The 550th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

THE ROYAL AERONAUTICAL SOCIETY

A Joint Meeting of the Royal Aeronautical Society and the Guild of Air Pilots and Air Navigators was held in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, October 6th, 1932, when Captain Norman Macmillan, M.C., A.F.C., A.F.R.Ae.S., presented a paper on "Air Navigation."

Mr. F. TYMMS, M.C. (Director of Civil Aviation in India), presided.

The CHAIRMAN: He would first express apologies on behalf of Mr. C. R. Fairey (President, Royal Aeronautical Society) for his absence, due to illness.

Introducing Captain Macmillan, the Chairman commented upon his splendid career in aviation and the solid practical work he had done, not only as a pilot, but in the particular subject of navigation. He had published a number of works on subjects which included navigation, all of which were well known. Further, Captain Macmillan had only just arrived in London, having flown from Oslo in order to present his paper.

AIR NAVIGATION

BY

CAPTAIN NORMAN MACMILLAN, M.C., A.F.C., A.F.R.AE.S.

The air flows past unseen as one flies. As it flows the invisible meridians and parallels pass with it, sharp but arbitrary demarcations imposed mathematically by man upon a sphere which he learned to measure long after he began to move intelligently about its surface; geographically non-existent hair lines which stubble the ends of certain radii projecting to the surface from the centre of our globe. But these same lines are cartographically displayed upon our maps, where we designate them graticules. And so the air navigator, resolving his position in the air above the surface of the earth as a mathematically unique point, knows both cartographically and geographically exactly where he is. Or should do!

And as this process is intended to be an exact science, all that would appear to be necessary to the navigator is a substantial knowledge of the methods of navigation and of how to put them into practice, all of which he can obtain from text books.

But whether considered from the point of view of the text book or that of the practical airman, air navigation is a large subject, far too large to be dealt with adequately in the short time at my disposal to-night, and I can only touch the fringes of it. It involves both theory and practice. Study is necessary to acquire a knowledge of the theory, while facility and speed can only be gained by hours spent in the air, and with the air pilot-navigator the almost subconscious realisation of the correct action to take is the summation of experience.

The combination of these two, knowledge and experience, makes the ideal pilot-navigator. In my attempt to express both it should be remembered that it is written for the pilot who is not yet an experienced navigator, rather than for the navigator who is already skilled.

Among the many subjects which are allied to air navigation there are some which are adequately dealt with elsewhere; with such I shall indicate the most profitable sources of information instead of filling these papers with that which is already obtainable. For example, it is not necessary to go into the detail of meteorology because works exist which cover it,[1] but where I have acquired personal knowledge of a practical nature not to be found in text-books I shall put it down.

Irrespective of distance, navigation consists in first knowing one's position, second knowing the position of the place to which one desires to travel, third being able to set a course from the first to the second, fourth being able to check one's position on that course as one travels, and fifth being able to arrive accurately at the point of destination.

Theoretical navigation is simple enough. The art lies in being what sailors call weather-wise in its actual practice in pilotage.[2] That is where the difference between pure theory and practice counts, and to this extent it must refer more to the pilot than to the navigator. In their profession most civil air pilots are akin to bridge officers of the Mercantile Marine. For the officer on the bridge is charged with the duties of checking position, maintaining course, and of seamanship. Most air pilots fulfil the same functions under less favourable conditions. Air pilots are also responsible for making harbour, that is, landing, whereas at sea there is a special body of men who carry out this work as local pilots.

The nearest corresponding case in aviation which I know of was when Mr. Levine made his romantic solo flight from Le Bourget to Croydon, and after he had made several desperate but unsuccessful attempts to land on the latter aerodrome, a British pilot went up in another plane to guide him in along a reasonable approach glide.

Position on the earth's surface is referred to in terms of latitude and longitude and any point so expressed is, and must be, unique. On our maps the meridians and parallels of latitude are shown as a graticule, and if we only had this graticule marked upon the surface of the earth, as well as on the map, the work of the pilot-navigator would be easy. Since nature has not provided this practical means to navigation (navigation in nature being little more than a wandering in quest of food and warmth), most pilots make shift with the landmarks which do exist equally upon map and landscape. The best natural landmarks are composed of woods, water, and hills, and when flying over or near really mountainous country it would be very useful for the air pilot to possess an oblique photographic or isometric chart of the mountain range so that he could identify the important peaks even at considerable distances, in much the same way that marine charts frequently show elevations of a coastline. The best artificial landmarks are railways and roads, but these should be used as checks to the course, not as actual guides. And so long as a course can be checked up by these aids there is little need to make use of other than D.R. navigation, except to indulge the whimsies of the crew. I have found that most pilots who lose their way when flying under these conditions do so because they become agitated about the non-arrival of the next landmark within their vision as early as they expected it to appear. They become impatient, search their maps for another landmark near where they imagine they are, find a good-looking one right or left on the map, turn off their course to discover it, don't succeed, and lose themselves. A little less imagination and a little more faith in their compass would have taken

[1] Pick: A Short Course of Elementary Meteorology.
Sir Napier Shaw: Manual of Meteorology. (For those who wish to go deeply into the subject.)

[2] The Practical Application of Navigation: Paper No. 262 at The World Engineering Congress, Tokyo, 1929, by Squadron Leader E. L. Johnston, O.B.E., A.F.C.

them on in most cases very near to their correct destination. When flying on a compass course a pilot must trust his compass, for in straight-line flight the compass is usually more reliable than counting the clock against landmarks, by which I mean estimating the ground speed made good prior to verification. When flying on a compass course and checking up on landmarks which only appear at intervals of perhaps 100 miles or more, the pilot should never lose heart if the clock appears to be getting the better of the compass. Let him keep on, and if his pre-selected landmark does not appear, let him search for and find another and determine where he is before he changes course.

The course should never be altered unless the pilot knows his position. That is fundamental. Two wrongs cannot make a right in navigation. Therefore, if an inexperienced pilot finds himself in the unhappy position of being lost he will be more likely to re-orientate himself knowledgeably by making a wide, sweeping circle in the search for a recognisable landmark which is marked upon the map than by making a definite angular change in course. Even if he is unsuccessful in finding such a guide he will come again to his original course, which will give him the advantage of being able to return approximately to his point of departure by flying on a reciprocal bearing, in which, however, he must make allowance for the angular change produced by the known or assumed drift component on the outward flight.

It is because the compass is more certain than the clock that long-distance trans-oceanic solo flights have been carried out on a single bearing course. The increase in mileage is not as great as one might expect. In the case of the course worked out by the Automobile Association for solo flights across the Atlantic the increased mileage was only about 10 to 16 in a great circle mileage of 1,880, a percentage increase of between .005 and .009.

The advantage of this method is obvious.

Because the earth is a sphere the great circle, or shortest route course, passes over the imaginary earth lines of the graticule (whatever it may do on a map projection) at a constantly-changing angle, except under conditions which I shall presently mention. But the compass is an instrument of plane geometry. Therefore, if a pilot wishes to fly a great circle course he must find the means to know when he has to change his course to meet the new conditions. When flying over oceans, forests, above clouds or through fogs, it is difficult to determine position with accuracy and rapidity unless an expert navigator is carried whose sole duty is to devote himself to this end. For the pilot-navigator it is impossible to do more than estimate position by D.R. This immediately involves him in the resolving of a number of factors which are possibly difficult to reconcile—drift, ground speed, track and distance from the last known position. While continuing to estimate his position he has to alter course at certain definite intervals, which may result in error. This alteration of course must allow for two things—the change in the great circle bearing and the change in magnetic variation. On a long flight on which the pilot must conduct his own navigation the chances of error are so great that it is far better to average them all before the commencement of such a flight and fly on a course of constant bearing, which is neither the rhumb line nor the great circle. The distance added thereby will most probably not be as great as that entailed by faulty D.R. on a great circle route, and, in the case of the route given above, it was less than the rhumb line by some 12 to 18 miles, due to favourable variation conditions. This may explain the Viking's success in trans-Atlantic navigation with a very crude sun compass. The constant bearing course offers other advantages to the pilot.

(1) The clock need not be considered except as an indication of approximate progress and expected landfall.

(2) Variation can be ignored.

(3) The curvature of the earth's surface can be ignored.

(4) Ground speed can be ignored except as a rough indication of progress.

The pilot then need only consider the matter of drift, for it is essential that he shall keep the course he has set so that he may reach the approximate point towards which he intends to fly. With this one variable to concentrate upon the pilot is far more likely to make a successful course than if he were to attempt to follow a whole series of rhumb lines changing at intended regular intervals about the curve of the great circle.

It will be clear, therefore, that drift is really the most important factor in pilot-navigation on a long-distance flight, and I will consider this question more fully later.

In the meantime it ought to be realised that this constant course method of navigation is not new. Merchant ship captains use it regularly for thousands of miles on some of the sea routes of the new world.

Also it should be clear that when the course lies due north or south, or east or west at the Equator, the rhumb line does actually coincide with the great circle, and at close approximations to courses on those tracks very little distance will be added by steering a constant course.

For this reason the only satisfactory maps for flying are those drawn on the mercator projection, because any straight line drawn thereon is a rhumb line which gives the compass course except for magnetic variation and deviation. On long flights the averaging of these three gives a constant compass course.

Of this projection I must just say a word. It was evolved by Gerard Kauffman in 1556. About 200 years later two English scientists, Bond and Wright, rediscovered the old formula and applied it. The central idea is simple. There is a constant scale of longitude. The scale of latitude increases outwards from the equator. The difference between the parallels of latitude varies as the secant of the latitude from one to infinity. Since it is based upon the equator it is not of use for navigation in the vicinity of the Poles, but the Norwegians go north as far as 85°N. lat. Parallels of latitude and meridians are projected as straight lines, and the course can be measured from any meridian. The scale of distance, however, is not constant and distances must be measured from the nearest vertical scale of latitude.

The mercator projection is the basis of practically all marine charts, and it is also the best basis for all aeronautical maps. It is not yet available for use near the Poles because travel in very high latitudes has almost invariably been confined to voyages of exploration. If, however, the polar routes are opened up in the future by means of aircraft I see no reason why polar charts should not be satisfactorily constructed on the mercator projection, using an arc of a meridian passing through the Pole as the unit base in the same way that the equator is used to-day. Since the north polar region is useful for the shortening of air distances in the geographical layout of the territories of the earth, it is of the greatest possible interest to possess such a chart.

After this digression from the main subject I must return to my point of departure.

So far I have only considered the long-distance straight line flight, but that—apart from its hazards of engine failure and change in weather conditions—is perhaps the easiest type of flight to engage upon so far as navigation is concerned, and, as has been seen, it can be reduced to the utmost simplicity by the employment of commonsense methods.

A far more difficult and in many ways no less hazardous form of navigational flight is that regularly practised by Fleet Air Arm reconnaissance aircraft in the conduct of their regular duties while at sea. These aircraft leave the aircraft carrier and proceed upon reconnaissance. They are probably required to fly to a certain spot, make observations from there over a given area—which involves the changing of course a number of times—and at the conclusion of the reconnaissance (which may have for its object the search for and spotting of enemy submarines, and be undertaken over sea always far out of sight of land) the return flight to the carrier (which in the interval may have changed position) along a course which was known before the aircraft left her deck. Here is a vastly different problem from that of straight line flight. And it always fills me with a certain sense of sardonic amusement that the straight line flying of aviators well known to the public earns far more honour and glory than work of a far more difficult character which is carried out unseen and often unheard.

This over-sea flying of naval aircraft requires the services of an officer who is carried as a navigator. Upon him devolves the duty of intimating the courses to the pilot and of knowing the exact position of the aircraft above the face of the waters at all times. He must also know at any moment the altered position of the carrier. The lives and safety of the crew depend entirely on navigation (except for the now greatly reduced risk of a forced landing on the water, for all these aircraft are land-planes). There are no landmarks. There are only the indicated speed and height, the course, the track and the clock, the observer's course-setting compass, drift-gauges, the course and distance calculator, the chart-board, and the wireless operator. Of course it may be argued that the wide range of vision obtainable from the air is a great help in returning to the ship. But there are times when the visibility on the return journey is very poor, even when the aircraft started out in good conditions, and I have been told of cases when the ship was not seen until the aircraft was almost over her. Perhaps if there are any Fleet Air Arm navigators present they will tell us something of their experiences.

In such flights the most important thing is to start right. The pilot and navigator know the correction of the air speed indicator for errors of height and pitot-head position. Compasses are most accurately swung and compensated. And, before taking off, the wind speed and direction are both known. When flying away from the ship the navigator takes most careful bearing sights upon her, and from these computes the course and drift—the first of which the pilot has already set. Thereafter it is a matter of D.R. navigation. The Carrier's position, course and speed are laid off along a line upon the chart. The aircraft's course and speed are laid off from the ship. The positions of both are plotted at regular intervals. When the first turning point is reached along this line the navigator has the new course plotted to allow for any change in drift, and along the new line the position of the aircraft is constantly plotted until the next turn, and so on, until the reconnaissance (observation for which is another duty of the navigating officer) has terminated. The navigator then estimates the distance from the aircraft to the position in which the ship will be by the time the aircraft has covered the intervening miles, lays off his line to intercept the ship's estimated position, works out the magnetic course and passes it to the pilot. Throughout the long leg back position is constantly plotted until at length the ship is sighted, and presently the affirmative signal is given and the aircraft goes down to alight.

This is perhaps as intricate a piece of work in aerial navigation as any that is called for upon the part of the air navigator. It requires exactness, patience, swiftness, and above all practice and confidence.

We have already discussed D.R. navigation. Astronomical navigation

consists simply in imposing a check upon one's D.R. Briefly described, the means of putting this into operation is as follows.

Astronomical Navigation

The altitude of a celestial body is the elevation of the body measured as an angle from the horizon towards the zenith. For this purpose some means of indicating the horizon is required. It is also necessary to know one's own altitude, since this will make a difference to the observed height. The difficulties of poor horizon and of height of flight have made astronomical navigation from aircraft less easy of accomplishment than from seacraft, added to which the increased speed of aircraft has made the problem of the time required for observation and calculation one of the utmost importance. It is desirable, therefore, to employ methods which reduce the work of calculation to the minimum.

The main requirements for astronomical navigation are first a sextant with which to measure the altitude of the heavenly body (the sextant developed for aircraft has an artificial horizon); second the Nautical Almanac, in which the necessary information with regard to the positions of the heavenly bodies is to be obtained; third a reliable chronometer, from which to obtain the local hour angle and hence the longitude; and fourth a book of the necessary conversion tables, and possibly a Bygrave slide rule for rapid calculation.

The theory of astronomical navigation is as follows: Suppose the altitude of any heavenly body is found to be 30°, then the zenith distance is 60°. The body is overhead at a point x on the earth's surface, and the observer is $60 \times 60 =$ 3,600 nautical miles from x. Therefore he is somewhere on the circumference of a circle about x, a circle which has a radius of 3,600 miles. The observation of a second heavenly body will produce a second circle cutting the first in two places; that nearest to the observer's believed position can be assumed to be his position.

In actual practice the dead reckoning position is known, and the normal method of astronomical navigation is that of laying down an observed azimuth from the body through the D.R. position and determining the position line at right angles to the azimuth. The zenith distance is observed and also calculated from the D.R. position. If the zenith distance is found to be greater by observation, a line is drawn at right angles through the azimuth in a direction away from the celestial body and a distance from the D.R. position equal to the difference between the observed and calculated zenith distances. If the zenith distance is less by observation, this line is drawn across the azimuth in a direction towards the celestial body from the D.R. position. For example, if there is a difference of 10 ft. between the observed and the calculated zenith the position line will be 10 miles along the azimuth from the D.R. position, in a direction determined by the factors given above. This line between D.R. position and position line is called the intercept.

It will be obvious that astronomical observations are only a check upon navigation to establish that the D.R. course is being maintained. All calculations which can be made on the ground prior to flight should be made; by working out in advance the assumed course, speed, and relative positions, together with the observations which may be expected to be required and their calculations, references to books of tables will be eliminated as far as possible when in flight.

The best book of tables for rapid astronomical navigation which the author has come across was first drawn to his attention by Captain Owens, of the ss. *Duquesa*. It is H.O. No. 208 Navigation Tables for Mariners and Aviators, by Lieut. Commander J. Y. Dreisonstok of the United States Navy. It is published by the Hydrographic Office of the United States Navy and can be purchased by anyone for 75 cents. The book requires only the addition of one

other book, the Nautical Almanac, to solve rapidly all navigation problems, regardless of the position of the heavenly body, whether it be sun, moon, planet, or star. The tables are simple to use, and require few figures. They give a quick solution for determining: (1) Line of position; (2) compass error; (3) meridian altitude; (4) great circle course and distance; (5) identification of unknown stars. All the tables required are contained in this small book of 87 pages, together with a full explanation of their use—and recapitulation here is unnecessary, for it would add too much to this paper.[3]

So much for the actual duty part of navigation. For those who want the theoretical side the paper as printed in the JOURNAL will supply it and it cannot be given now as though this were a classroom. But there are other things to consider here.

The compass is the heart of navigation. It is the duty of every pilot and navigator to know that the compass in his aircraft is well positioned so that: (1) He can read it easily under all conditions; (2) it is not interfered with by local attraction in the aircraft; (3) that it is swung at regular periods if used over the same routes; (4) that it is swung after changes in locality involving different conditions; (5) that it is swung after heavy landings; (6) that any compensation is made with the minimum number of correcter magnets so that the directive force is not rendered unnecessarily sluggish.

I shall give one example of carelessness, due to ignorance, I am afraid. A long-distance flight was contemplated. The usual single compass was fitted. Someone asked the pilot what would happen if his compass failed. It was a contingency he had not thought of. So that no such possibility should arise to endanger the aircraft and her crew the pilot mounted three compasses in a triangle, all close together and on the same plane. He felt that the chance of all failing was very remote. He did not appreciate that each was interfering with the action of the other, and that while the chance of a breakdown might have been lessened the possibility of accurate compass direction was ruined in each one. That flight ended in disaster.

I have promised to refer to drift, and I shall do so here—for drift is the great enemy of the compass. When flying a true course the compass reading can only indicate the direction in which the head of the aircraft points. The faults of variation and deviation have already been got over by making corrections to the compass reading to allow for them, and if it were not for meteorological conditions, nothing more would be required for the pilot to make a straight line flight to any part of the earth.

Of these meteorological enemies fog is the greatest enemy, for although blind flying instruments and practice in blind flying have been developed to a stage where the pilot need not fear to fly through fog, yet there are three main evils yet to be overcome.

(1) The absence of a height indicator which shows the actual height above the territory flown over.

(2) The possibility, under certain conditions of fog, of ice formation on the wings.[4]

(3) The difficulty of making harbourage.

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[3] See also paper by P. F. Everitt on "Tables for use in Aero Navigation by Astronomical Methods," R.Ae.S. Journal, and the book of Navigation Tables by John E. Gringrich, U.S. Navy, entitled "Aerial and Marine Navigation Tables."

[4] "The Formation of Ice upon Airplanes in Flight," by Thomas Carroll and William H. McAvoy. N.A.C.A. Technical Note No. 313.
"The Prevention of the Ice Hazard on Airplanes," by Wm. C. Greer and Merit Scott. N.A.C.A. Technical Note No. 345.

A second enemy is down draught, and I found even in Europe this phenomenon so severely active that I have scarcely been able to continue my flight. In other parts of the world it has caused fatal accidents, and others which fortunately have not ended in tragedy. This phenomenon usually occurs near mountains, or where steep slopes fall down to lakes or sea

On one occasion when flying an Avro 626 just above the top of the canyon through the Andes mountains I was forced down for 1,000 feet against full throttle by quite a gentle northerly wind blowing down the slope of Aconcagua. I got out of the down draught by flying close to the lee wall of the canyon. On another occasion a plane carrying passengers from the Argentine to Chili struck an up current at 17,000 feet. The plane was forced up to 24,000 feet and all the passengers fainted in the cabin.

The third great enemy is the drift caused by windage, the angular relation between the course and the track. Admittedly, when one is flying over country plentifully supplied with landmarks and in conditions of reasonable visibility it is easy enough to check drift and compensate for it. Above the regular air routes wind strength and direction are both measured and reported at regular intervals, so that the air pilot is advised of the conditions before he commences his flight, and when he is equipped with wireless he can obtain reports during flight. But above the wilder spaces of our earth's surface this service is not available and the air pilot-navigator is forced back on his own resources. Indications of ground wind —which in many countries can be obtained from windmills, dust raised by animals, smoke, the light and shade on grass, etc.— are not of much value, for the ground wind may blow in several different directions in quite small areas owing to conditions of local disturbance—the effects of folds in the ground, hills, houses, trees, variations in temperature, etc. Moreover, the ground wind is rarely the same in direction as the geostrophic wind which blows at 1,500 feet above the surface, and in which the airman is more likely to be flying. Cloud shadows may be used upon occasion to indicate the wind direction at cloud level, but the pilot may not want to fly at that height.

When the ground is observable the experienced airman can obtain a very good indication of what is happening by direct observation. He can also check both wind direction and force by changing course and measuring and plotting his resultant drifts in three directions. When he carries a navigator the latter can measure the drift angle by observations by means of a bearing plate or by sights over the tail upon some distinctive object in the landscape. When he flies beneath a clear sky the pilot or navigator can maintain correct direction by sights of sun or stars; when flying above the sea, by the line of spume that is blowing by the wind from the running waves. When flying above or through broken clouds, or clouds which leave a gap or hole, touch can be maintained with Mother Earth. But when buried in thick clouds, shut in from all sight of earth, sea or sky, he can do no more than continue upon the course he flew when first he entered them. Fortunately, in conditions of deep fog the air is usually still and drift can be discounted. There is one help, however, in the worst conditions —wireless, and no long-distance flight is properly equipped to make the journey without that aid to navigation, which can only be discarded by the crew by increasing the hazards which they run.

In the present-day pilot's training blind flying is an essential. The secret of blind flying is the effacement of the older visual methods and the application of flight by instruments alone to enable the pilot to maintain and change direction, along a stable flight path.[5] The essential additional instruments are the turn and bank indicator and the fore and aft inclinometer. Opinions among pilots

[5] "Spiral Tendency in Blind Flying," by Thomas Carroll and William H. McAvoy. N.A.C.A. Technical Note No. 314.

are divided as to the best instruments among those available for this purpose, and I do not propose to raise controversy upon this subject here. But any all-weather pilot is almost certain to have to fly blind sooner or later, and to-day every aircraft ought to be fitted with the necessary instruments, while every pilot ought to be conversant with their use in practice. In this connection I look forward to the day when aircraft will be as completely equipped in their standard instrument board layout as is the modern motor car at a standard selling price.

Blind flying can be and usually is considered as the reduction of pilotage from visual flight to instrument flight. This is true so far as school work is concerned and in training practice this change confronts the pilot (and very often the experienced pilot no less than the beginner) with difficulties. For example, the behaviour of the compass is far more perplexing in blind than in visual flying, particularly when northerly changes are required.

But blind flying as applied to air navigation is more intricate than school blind flying. So far as the pilot is concerned it may be described as eight dimensional. Let me enumerate these dimensions for the sake of clearness.

(1) Lateral stability.
(2) Directional stability.
(3) Longitudinal stability.
(4) Speed.
(5) Time.
(6) Orientation in space.
(7) Geographic orientation.
(8) Height.

The turn indicator and pitch indicator enable the pilot to measure the three which affect stability in flight. The compass enables him to measure orientation in space, although the ordinary magnetic compass is not wholly satisfactory in this respect. Speed, time, geographic orientation and height can only be computed. Speed made good, track, height and hour angle are therefore the unknown factors. The use of D.F. wireless or radiogoniometry may serve to solve three of these, but as yet no reliable instrument has been produced to indicate true height above the surface flown over. And it appears reasonable to assume that the application of blind flying to the needs of the world-ranging pilot-navigator cannot be considered as wholly solved until instruments are produced which will enable him to deal with all the factors involved and that as far as possible independent of operators external to the plane.

Even that leaves the problem of blind landing still unsolved—the most dangerous operation which the pilot can be called upon to undertake. Perhaps the application of television to produce on the pilot's dashboard a picture of the aerodrome which he is approaching may solve the problem of the unseen landing ground. But the danger of the intermediate landing will remain until we can enable the pilot to see through an obscured atmosphere.

On thoroughly organised air routes blind flying has already reached a *reasonable* measure of security which justifies its continuance, but this cannot be said of routes which are not so organised. And the pilot who sets out to fly really blind over wild country with his present equipment and without organised ground assistance always makes me think of the famous nameless Mr. X, who, while enjoying a particularly jolly party abroad, suddenly announced about one o'clock in the morning that *he* could fly without wings, whereupon he promptly took a header straight out of a two-floor window! He was very lucky to get off with only a sprained ankle.

To the younger generation of pilots who are just beginning to get about the country or the Continent on cross-country flights, the earlier days of hazard are gone. The time when a long cross-country or trans-Continental flight was an adventure has passed. The aeroplane of to-day is a reliable vehicle when handled with intelligence, and the very able work of the post-1926 (shall we say?) pilots forms a striking tribute to the high degree of intelligence possessed by the present air pilot.

But every pilot ought to study carefully on the ground as well as in the air. Situations likely to arise must be thought out beforehand. What shall be done if caught in fog; how to recognise the peculiar bumps that presage thunderstorms; that wind changes direction with height and with sudden changes in temperature; that prevailing winds in the northern hemisphere are westerly at height; that waves do not always run with the wind, but that when breaking into white horses in open water they do run before the wind; that churches are built to head to the east; that the lee side of mountains must be treated with the utmost caution, while the windward side is as good as a bigger engine; that all map projections do not give a compass course as a straight line; and that thorough preparation before a flight is the best guarantor of successful navigation.

Finally, for aerial navigation I reiterate what I have already said before this Society,[6] that the two instruments which we most require to assist us in air navigation are a speed indicator which indicates the true air speed at all heights and a height indicator which really tells us the height at which we pass above the surface over which we are flying.

There are many sides to the question of air navigation with which I have not been able to deal in this short paper, but these will be dealt with in the further material which will appear in due course in the JOURNAL.

I.—TERMINOLOGY

It is always difficult to know where to begin such a subject as this; I assume, however, that the reader does not expect information herein upon the operation of flying an aircraft, the use of logarithms, or the use of the slide rule.* The use of logarithmic tables is required for the solution of problems in navigation. The slide rule is invaluable as an aid to rapid calculation.

First we must know the terms which are used in navigation together with the physical basis of the whole subject, the spherical configuration of the earth's surface.

The Earth is considered for all practical purposes as a sphere.

A Great Circle is *any* circle on the earth's surface whose plane passes through the earth's centre and thus divides the sphere into two equal parts. The shortest distance between two points on the earth's surface always lies along the arc of a great circle.

Length of Arc of a great circle is measured by the angle subtended by the radii of the arc at the centre of the circle, therefore it is an angular distance.

The Poles.—The axis is the diameter about which the earth revolves, and the poles are the ends of the axis where they meet the surface of the sphere.

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[6] The Art of Flying Landplanes and Seaplanes. R.Ae.S. Journal.

* Swoffer: *Learning to Fly*. Pitman.
Henderson: *A Complete Course in Practical Flying*. John Hamilton.
Macmillan: *The Art of Flying*. Duckworth.
Any book of Logarithmic Tables.
Instructions for the use of the Slide Rule.

The Equator is a great circle on the earth's surface, every point of which is equidistant from the poles.

A Meridian is a semi-great circle joining the poles.

A Small Circle is *any* circle on the earth's surface whose plane does not pass through the earth's centre.

A Parallel of Latitude is a small circle on the earth's surface which is parallel to the equator.

Latitude is the length of arc of any semi-meridian, measured from the equator north or south, and expressed as the angle subtended between the radii running from the earth's centre to the equator and to the parallel of latitude passing through the other end of the arc.

A Prime Meridian is an arbitrarily fixed semi-meridian which is the zero from which longitude is measured. The semi-meridian of Greenwich is usually adopted as the prime meridian.

The Ante-Meridian is the semi-meridian which with the prime meridian completes the great circle.

Longitude is the length of arc subtended at the equator between the semi-meridian passing through any point and the prime meridian.

Latitude and longitude, then, are the spherical co-ordinates by means of which any point on the earth's surface can be defined uniquely and without ambiguity. By use of these co-ordinates position is expressed.

Difference of Latitude is the arc of the meridian intercepted between the parallels passing through any two places. It is written D. Lat.

Difference of Longitude is the arc of the equator intercepted between the meridians passing through any two places. It is written D. Long.

Departure is the linear distance east or west of a meridian. It is written Dep.

The Statute Mile is a unit of measurement arbitrarily fixed in Queen Anne's reign as 5,280 feet = 1 statute mile.

The Nautical Mile is the mean length of a minute of latitude. The circle is divided into 360 *degrees*, each degree is divided into 60 *minutes*, and each minute is divided into 60 *seconds*. Therefore there are 21,600 nautical miles in each great circle. The mean length is taken because the earth is not a true sphere, and the mean is selected at about 45 degrees. The degree is written thus °, the minute thus ′, and the second thus ″. The mean length of the minute of latitude is 6,080 feet = 1 nautical mile.

Since the earth's radius has been determined by pendulum motion as 3,960 statute miles, we can express the relationship between the statute and nautical mile by the rule of $2\pi R$, thus:—

$(2 \times 3.14 \times 3{,}960 \times 5{,}280)/(360 \times 60) = 6{,}079$ feet = 1 Naut. mile = 1 minute.

The Kilometre is the 1/10,000th part of the quadrant. Its mean length at the earth's surface is equal to 3,280 feet.

A Knot is a measure of speed in nautical miles per hour.

The Compass is the instrument by which direction is maintained. Within the limitations of the instrument it permits a steady course to be followed.

The Course is the direction in which the aircraft's head is pointing, measured as a horizontal angle from the meridian. It may be either True course, Magnetic course, or Compass course. The meaning of these expressions will be explained later.

The Track is the actual line over which the aircraft flies.

Drift is the difference between the course and the track. It is expressed as an angular measurement, and with aircraft it is due to wind force when the latter does not coincide in direction with the course.

The Track Angle (or the course made good) is the angle from either the true or the magnetic meridian to the track.

Air Speed is the speed at which the aircraft passes through the air.

Wind Speed is measured in miles per hour and its direction is given in degrees from true north.

Ground Speed is the actual speed made good over the ground.

Magnetic North is the direction in which a freely suspended magnet lies in the northern hemisphere. In the southern hemisphere a freely suspended magnet points to the South Magnetic Pole. This question will be fully dealt with later.

Graticule.—The lines on a map representing latitude and longitude.

Grid.—The rectangular co-ordinates on a map which are used for the purpose of measurement.

We have seen that by means of the spherical co-ordinates of latitude and longitude it is possible to describe the position of any point on the earth's surface. The shortest distance between any two points will lie along a curved line which is the arc of a great circle. Since the ideal in navigation is to follow the shortest possible route from start to destination, let us see how this is dealt with in actual practice.

Whatever one's position on the earth's surface, the semi-meridians interconnecting the north and south poles are the indices from which direction is measured as a horizontal angle. Therefore any great circle which maintains a constant angular relation with these meridians provides not only the shortest route but a constant track angle. This property is only found when travelling due north or south, or when travelling east or west *at the equator only*. All other great circles provide the shortest route, but the track angle continually changes. The compass (which is the instrument used to maintain direction) within its limitations of magnetic variation indicates a geometrically constant course in still air. It will be clear, therefore, that it is only under exceptional conditions that a constant compass course can be maintained when travelling along great circle tracks. Under ordinary conditions the compass does not indicate the great circle but an oblique line which, crossing all meridians at a constant angle does not point to the destination. This divergence is due to the fact that the compass is an instrument of plane geometry, while the surface of the earth is spherical. The compass line is called the *Rhumb Line*. Since there is no other instrument available for the navigator and since it would be inconvenient to change course continually, the practice is to steer along a *series* of rhumb lines which follow the path of the great circle and to neglect the discrepancy which exists. In particular cases both in the air and at sea it is also perfectly feasible and sometimes desirable to steer a constant rhumb line course over very long distances. For a pilot flying solo, or unaccompanied by a skilled navigator, across large expanses of water or desert or forest there may be no alternative.

II.—Maps and Charts

A map or chart is the first requirement of the pilot navigator. Now, since all maps and charts are simply the projection of the earth's spherical surface on to a flat plane, it is obvious that distortion must occur as a result of the conversion. There are many projections, each having some particular virtue which has

brought about its creation. Some are suitable for navigation while others are not.

For the navigator the two most important projections are the Mercator and the Gnomonic, although there are others with which the air navigator must be acquainted.

The Mercator Projection.—On this projection both the parallels of latitude and the meridians are projected as straight lines, and any straight line drawn upon this projection is a rhumb line or line of constant bearing. The course can be measured from any meridian. There is no constant scale of distance and distances must be measured from the nearest vertical scale of latitude. The number on the bottom right hand corner of a Mercator chart is the index number of the chart. The correction dates are shown in the bottom left hand corner. The circles on the chart are called compass roses. The black or blue lines are called *isogons*, the name for the lines of equal magnetic variation. Red blobs represent lights. The dotted lines around the coast are fathom lines, the fathom being a nautical unit of vertical measurement of six feet. The figures dotted over a marine chart are soundings.

Practically all marine charts are produced upon Mercator's projection, the area and scale of the sheet being adjusted to the shape and area of the waters to be charted. With marine charts the variations in size, shape and scale do not permit them to be joined together to form a complete whole. Nevertheless, any number of sheets of Mercator's projection may be joined together provided that they are constructed with degrees of longitude of equal length.

Mercator's projection has been chosen for the general sheets of the International Aeronautical Maps. These maps give two graticules, the longitude from the meridian of Greenwich and the longitude east from the ante-meridian of Greenwich. Latitude is measured vertically from the south pole to 180° at the north pole. All aerial information is printed in black, the spherical co-ordinates, names of places, aerodromes, wireless stations, lighthouses, prohibited areas, danger areas, compass roses, etc. Red is used to denote railways, towns, overhead high power cables and anything which may be a danger to aircraft. Roads and tracks are shown in sepia. Water is blue; woods dark green. Contours are delineated on the layer system by neutral shading with the addition of spot heights in thousands of metres, thus 1.3 = 1,300 metres. The decimal point is the height spot in addition to the decimal of thousands of metres. Buff has been adopted as the basic colour for sterile country, and pale green for fertile country. Conventional signs are used to show the surface features and with these the pilot navigator should make himself familiar.

The Gnomonic Projection is a natural projection which assumes one to be at the earth's centre looking outwards, and all meridians and parallels appear as they would if they were painted on a glass sphere lit up from the outside. The scale increases in every direction from the tangential point of projection, to infinity at 90° from that point. Hence it cannot be used for measuring distances. The projection is of value because any straight line drawn on it is the arc of a great circle, but bearings are correctly to be measured only at the centre of projection. These bearings are great circle bearings, which may also be called azimuths. The value of this projection is limited to the laying down of a great circle track for the purpose of studying the line followed by the great circle.

The Conical Projection has various forms, for example, the polyconic one-standard and the polyconic two-standard. The conical projection is mostly used for continental maps. It is obtained by enveloping the sphere with a cone until it touches. Good representation of relative geographical size and shape is projected. The straight line, however, is neither a rhumb line nor a great circle, although it approximates more nearly to the latter. The exception is the meri-

dian. In this projection the meridians are straight lines converging towards the poles. They are therefore both rhumb lines and great circles. In measuring bearings on this map a measurement close to that of the rhumb line is obtained by taking the bearing at the meridian crossing the straight line mid-way between the two points. The maximum divergence of the rhumb line from this straight line occurs at this same point. The divergence is maximum on east-west courses, and increases on sheets near the poles. Therefore any straight line laid down will not be the line followed by the aircraft except when flying north and south. This projection is used for the International Geographic series of maps, in which each sheet is constructed on its own central meridian. Sheets in the same latitude can be joined, as can any four adjoining sheets, but strips of different latitude cannot be joined. Distances can be measured on the scale of latitude. With reasonable precautions this map may be used conveniently for navigation. The scale is 1/1,000,000, almost sixteen miles to the inch.

The Ordnance Survey of Great Britain series of maps is constructed on a trigonometrical survey to a measured base line. Strictly speaking, it is not a projection; the spherical co-ordinates are delineated by the formulæ of the French cartographer Cassini, hence it is frequently called the Cassini projection. The straight line is neither the rhumb line nor the great circle, and bearings have to be taken as with the International 1/1,000,000 Polyconic series, that is on the central meridian in relation to any straight line joining two points. The meridians are not parallel to the sides of the map and bearings cannot be taken with reference to the edges of the map. The maximum divergence occurs on east-west courses. The scale is four miles to the inch, or 1/253,440. Distances are measured on a scale of statute miles.

Map Scales

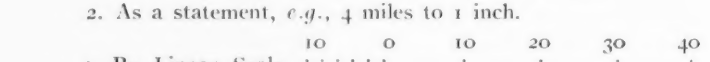
The scale of a map is the relation between a unit of length on the map to a stated number of the same units on the ground. It is expressed in three ways.—

1. As the R.F., or Representative Fraction of a map, which is given as follows:—

   1/63,360 which is equal to 1 inch/1 mile.

2. As a statement, *e.g.*, 4 miles to 1 inch.

3. By Linear Scale.



Conversions are carried out as follows:—

The statement is 4 miles to 1 inch. What is the R.F.?

$$1/(4 \times 5{,}280 \times 12) = 1/253{,}440.$$

The statement is 10 miles to 1 inch. What is the R.F.?

$$1/(10 \times 5{,}280 \times 12) = 1/633{,}600.$$

Express as a Statement the R.F. 1/200,000.

$$200{,}000/(5{,}280 \times 12) = 200{,}000/63{,}360 = 3.15 \text{ miles to 1 inch.}$$

To construct a Linear Scale to measure the distance in statute miles for the R.F. which is given as 1/300,000.

Example:—

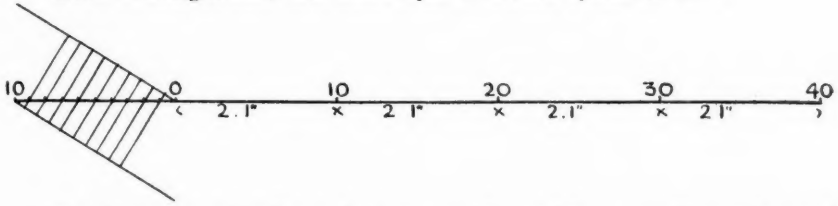
$$300{,}000/(5{,}280 \times 12) = 300{,}000/63{,}360 = 4.725 \text{ miles to 1 inch.}$$

Then calculate the unit inches for 10 miles as convenient to work to:—

$$4.7 \overline{)\ 10\ (=47\ )\ 100\ (\ 2.1 \text{ inches}}$$

$$\underline{94}$$

Draw a straight line, then mark upon it several spaces of 2.1″.



To obtain the unit miles scale draw two diagonal lines, one from either end of the left 2.1″ division, with a ruler or parallel ruler; then divide each diagonal line into spaces of any equal measurement, one less than the number of divisions required on the base line; connect up across the base line. Index the miles in tens, beginning from the right of the first division as zero, ten miles to each 2.1″ division.

To construct a Linear Scale to measure the distance in statute miles for the R.F. which is given as 1/1,000,000 by logarithms.

Example:—

1/1,000,000 1,000,000/(5,280 × 12) = 1,000,000/63,360

6.000000

4.801815

1.198185 = 15.78

15.78 miles = 1 inch.

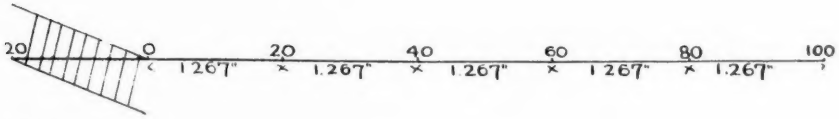
Correct to 20 miles to obtain a convenient scale.

15.78) 20.00 (= 20.00/15.78 = 3.301030

3.198185

0.102845 = 1.267″

20 miles = 1267″



Map Projections

Conical Projection. Example of construction.

Construct a map to preserve a constant scale of latitude so that 1° of latitude = 6 cms. between the parallels of 45° N. and 47° N. and longitude 5° W. and 7° W. Make use of the logarithmic table book.

$$\frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Lat.}$$

Dep. = D. Long. × Cos Lat.

= 6 cms. × Cos 45°

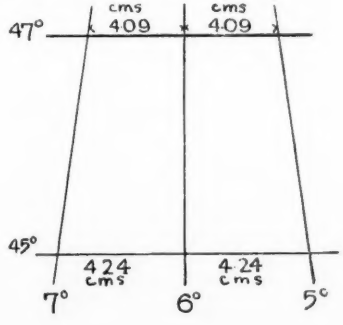
= 6 × 0.707107

= 4.2426

6 cms. × Cos 47°

= 6 × .681998

= 4.091988



Cylindrical Projection.

This projection varies as the tangent of the angle. Since it is a projection in which the air navigator is not greatly interested it is unnecessary to go into the method of construction in detail.

Mercator Projection. Example of construction.

The Mercator projection varies as the secant of the angle and is calculated to every half second.

Construct a Mercator map projection to preserve a constant scale of longitude so that 1 degree at the equator = 6 cms. Construct the projection between the parallels of 45° N. and 47° N. latitude, and 5° E. and 7° E. longitude.

$$\frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Lat.}$$

Find D. Long. $= x$.

Then $x = \dfrac{\text{Dep.}}{\text{Cos Lat.}} = \dfrac{6 \text{ cms.}}{\text{Cos } 46^\circ}$

$= 6 \text{ cms.} \times \text{Sec } 46^\circ$

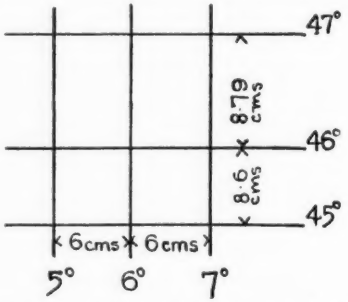
$= 6 \times 1.43956$

$= 8.63736$

$6 \text{ cms.} \times \text{Sec } 47^\circ$

$= 6 \times 1.46628$

$= 8.79768$



Construct a chart on Mercator Projection on a scale of 10 cms. = 1° of longitude at latitude 0. The chart to be constructed between the parallels of 47° N. and 49° N. latitude and 15° E. and 17° E. longitude. Use the meridional parts from the Table Book.

Example:—

Meridional Parts.

47 = 3,203
48 = 3,292 Difference 89
49 = 3,382 ,, 90

1° of long. at lat. 0 = 60′ of Arc at the Equator.

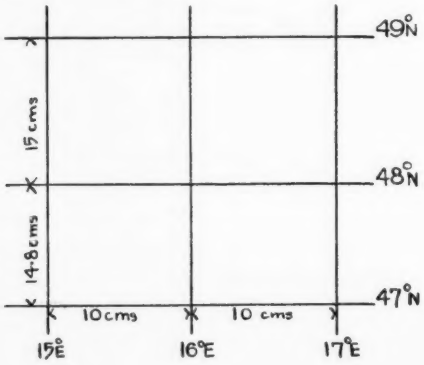
If 60′ of Arc at the Equator = 10 cms. what will 89 equal?

$(89 \times 10)/60 = 14.8$ cms.

What will 90 equal?

$(90 \times 10)/60 = 15$ cms.

From these figures construct the chart.

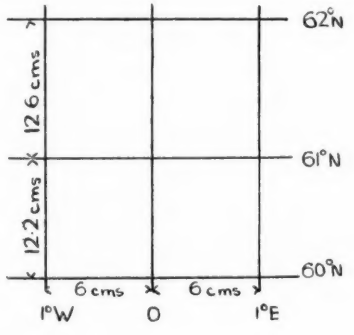


Construct a Mercator Chart between 60° N. and 62° N. lat. and 1° W. and 1° E. long. on a scale of 1 mm. = 1 minute of long. at the Equator.

Example:—

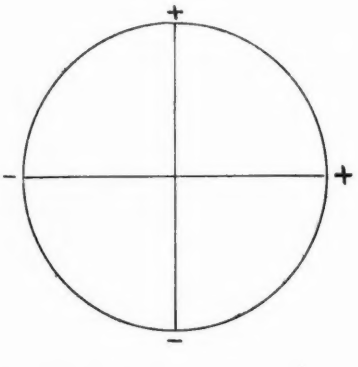
Meridional Parts.

60 = 4,527
61 = 4,649 Difference 122
62 = 4,775 ,, 126
(122 × 60)/60 = 122
(126 × 60)/60 = 126

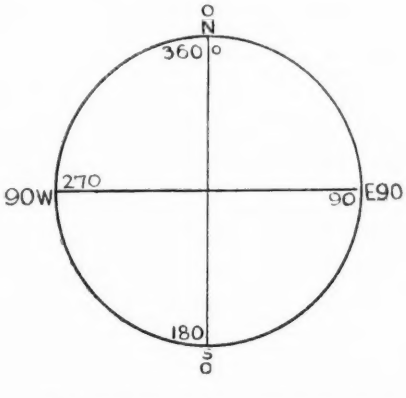


The Quadrant

We have two methods of dividing the circle for triangulation, one the algebraic and the other the sexigesimal. Angular measure by the sexigesimal method divides the circle into quadrants each containing 90 degrees, written 90°, each degree is divided into 60 minutes, written 60′, and each minute into 60 seconds, written 60″. In the quadrant there are 90°, or 5,400′, or 324,000″.

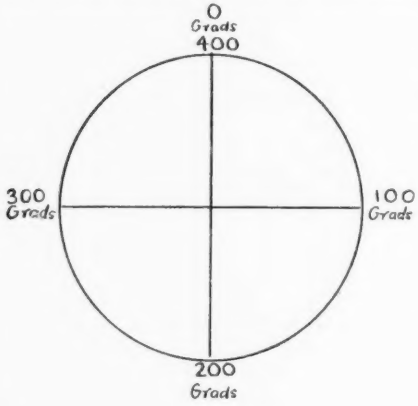


With the algebraic, left above, all lines running up and to the right are + values, and all lines running down and left are minus values. This method is clumsy. It is avoided by the navigator by considering only the top right hand quadrant so that the values always remain positive.



The method of the navigator is to fold the circle in such manner that the required triangle falls in the top right quadrant. The marine compass is orientated as shown above, but the air compass was graduated into 360° in 1913. This graduation is shown concentrically inside the marine orientation.

The Centesimal System of Circular Measure (French).



The centesimal system divides the quadrant into 100 grads and the circle into 400 grads. Each grad is subdivided into 100 kilometres, and each kilometre into 1,000 metres. The quadrant then contains:—

100 grads, written thus 100^{G}.
100

10,000 kms., ,, $10,000^{\prime}$.
1,000

10,000,000 metres, ,, $10,000,000^{\prime\prime}$.

$27^{G}\ 1^{\prime}\ 1^{\prime\prime}$ can be written in the metric system thus, $27^{G}.01001$.

The Conversion of Sexigesimal to Centesimal Measure.

Grads to Degrees $\frac{90^{\circ}}{100^{G}} = .9$ multiple.

Degrees to Grads $\frac{100^{G}}{90^{\circ}} = 1.1$ multiple or reciprocal $\div .9$.

When converting from degrees to grads the reciprocal is used to avoid the inaccuracy resulting from the repeating decimal.

When converting it is necessary to convert minutes and seconds into decimals of degrees and *vice versa*. The rule for the conversion is to divide the minutes and seconds by 6 when converting from degrees to grads, and to multiply by 60 when converting from grads to degrees, thus:—

Examples.—How many grads are there in $35^{\circ}\ 25^{\prime}\ 36^{\prime\prime}$? (Reduce the minutes and seconds to decimal, then divide by .9.)

$\div 6 \mid 35^{\circ}\ 25^{\prime}\ 36^{\prime\prime}$
$\div .9 \mid 35.416$
39.35

Therefore $35^{\circ}\ 25^{\prime}\ 36^{\prime\prime} = 39^{G}\ 35^{\prime}$.

Convert $25^{G}\ 16^{\prime}\ 051^{\prime\prime}$ to degrees.

$25^{G}.16051$
$\cdot 9$
22.644459
60
38.667540
60
40.052400

Therefore $25^{G}\ 16^{\prime}\ 051^{\prime\prime} = 22^{\circ}\ 38^{\prime}\ 40^{\prime\prime}$.

III.

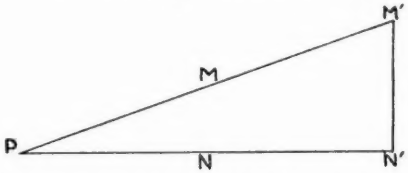
Theory of Navigation with Solutions to Practical Problems

Trigonometry

An angle is formed by the inclination of two lines, one to another. Joining these lines forms a triangle.

If the sides A and C be each extended an equivalent distance beyond the side B and connected by the line B′, we find that magnitude can be increased without interfering with dimensional equality. We find that $A=A'$, $C=C'$, $2B=B'$.

In the triangle PMM′N′N we find the following equations:—

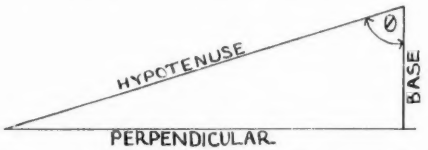


$$\frac{MN}{PM}=\frac{M'N'}{PM'}=\frac{2MN}{2PM}=\frac{MN}{PM}$$

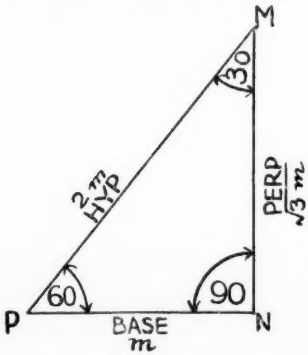
$$\frac{PM}{PN}=\frac{PM'}{PN'}=\frac{2PM}{2PN}$$

Convention which Covers all Right Angle Triangles.

In any right angle triangle the side opposite the angle under consideration is called the Perpendicular; the longest side is called the Hypotenuse; and the remaining side is called the Base. This is shown below:—



Certain terms are used in trigonometry. These are Sine, Cosine, Tangent, Cosecant, Secant, Cotangent. Each term refers to a particular relation in the triangle. These relations are shown below:—



$\frac{\text{Perp.}}{\text{Hyp.}}\ \frac{MN}{PM}$ Sine. $\qquad \frac{\text{Hyp.}}{\text{Perp.}}\ \frac{PM}{MN}$ Cosecant.

$\frac{\text{Base}}{\text{Hyp.}}\ \frac{PN}{PM}$ Cosine. $\qquad \frac{\text{Hyp.}}{\text{Base}}\ \frac{PM}{PN}$ Secant.

$\frac{\text{Perp.}}{\text{Base}}\ \frac{MN}{PN}$ Tangent. $\qquad \frac{\text{Base}}{\text{Perp.}}\ \frac{PN}{MN}$ Cotangent.

There are certain mnemonic doggerels to help memorise these terms:—

$\frac{\text{Perp.}}{\text{Hyp.}} = \frac{\text{Pat}}{\text{Has}}$	= Sine.	$\frac{\text{Has}}{\text{Pat}}$	= Cosecant.	Sign of a Public House.
$\frac{\text{Base}}{\text{Hyp.}} = \frac{\text{Brought}}{\text{Her}}$	= Cosine.	$\frac{\text{Her}}{\text{Brought}}$	= Secant.	Cost of a Barrel of Hops.
$\frac{\text{Perp.}}{\text{Base}} = \frac{\text{Pigs}}{\text{Back}}$	= Tangent.	$\frac{\text{Back}}{\text{Pigs}}$	= Cotangent.	Tan of a Pig's Back.

The main mnemonic is: *Pat has brought her pigs back.*

The whole principle of navigation is:—

The considered angle = The Course.
The Perpendicular = The Departure.
The Base = The Difference in Latitude.
The Hypotenuse = The Distance.

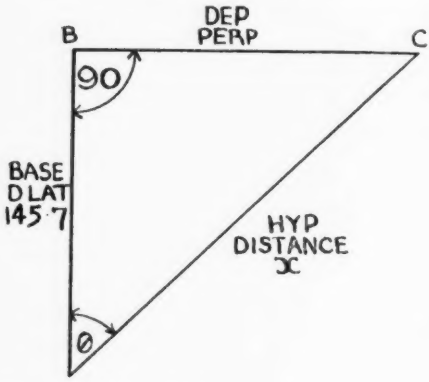
There are two possible cases:—

1. Given two sides to find an angle.

   Method of working: Form a fraction with the two given sides and determine the trigonometrical ratio. Evaluate this fraction as above and take the value of the angle from the table of trigonometrical functions.

2. Given one side and one angle to find a side.

   Method of working: Place required side over the given side and find the trigonometrical function. Then equate. Bring the required side over to the left and multiply the trigonometrical function by the given side. The result is the side you want.



Case 1. *Solve Course.*

Form a fraction with the two given sides and determine the trigonometrical ratio.

$$\frac{\text{Perp.}}{\text{Base}} = 169.4/145.7 = \tan\ \theta.$$

Evaluate this fraction

169.4/145.7	2.228913
	2.163460
	10.065453

Take the value of the angle from the table of trigonometrical functions.

$\theta = \tan\ 10.065453 = 49^\circ\ 18'$
Therefore Course $= 49^\circ\ 18'$

***Case* 2.** *Solve Distance.*

Place the required side over the given side and find the trigonometrical function.

$$\frac{\text{Reqd. side}}{\text{Given side}} = \frac{x}{\text{Base}} = \frac{\text{Hyp.}}{\text{Base}} = \text{Sec}\ \theta$$

Mnemonic. $(6/3 = 2) = (6 = 3 \times 2)$

Therefore Hyp. = Base × Sec θ = 145·7 × Sec 49° 18′.

Bring the required side over to the left (as above) and multiply the trigonometrical function by the given side.

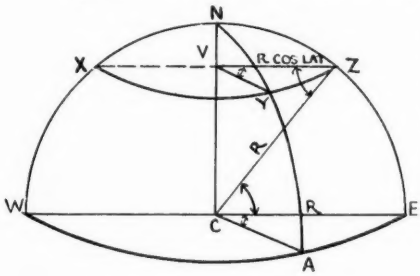
Take number	Log. of 145.7	2.163460
,, secant	,, 49° 18′ ...	10.185687
Add and remove unnecessary index		12.349147

Find the Natural number of Log. and read off 223.4.

Therefore distance = 223.4

Determination of Departure.

Departure is the linear distance east or west of a meridian.



ECZ = the latitude of Z. Therefore the angle VZC is also equal to the latitude of Z. R = radius and is constant. The difference of longitude between Y and Z is equal to the difference of longitude between A and E. But the linear distance between Y and Z is obviously less than the linear distance between A and E. Therefore it is necessary that we find the relationship between linear distance along a parallel of latitude and the difference of longitude along the equator. Because the angles at the centres of the two horizontal planes remain constant, we can form a relationship between adjacent sides in the two angles.

The radius CE of the equator remains constant and is equal to R.

The angle VZC is equal to the latitude.

The radius of the small circle XYZ = VZ/R = Base/Hyp.

Since Base/Hyp. = Cos VZC, therefore VZ = R Cos Lat.

This enables us to form a relationship between YZ (which is departure or linear measure) and AE (which is difference of longitude or angular measure) as follows :—

$$\frac{\text{Departure}}{\text{D. Longitude}} = \frac{\text{R Cos Lat.}}{\text{R}}$$

Therefore Departure = D. Long. × Cos Lat.

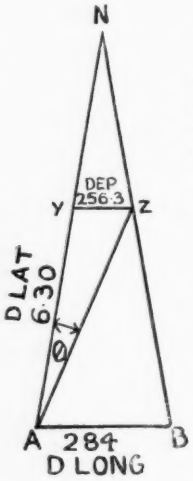
The practical application of this theory is exemplified in the following problem :—

From A in Latitude 20° 15′ N. Longitude 15° 16′ E.
To Z ,, 30° 45′ N. ,, 20° 00′ E.

Find (1) Departure, (2) Course, (3) Distance.

The solution is as follows :—

	20° 15′ N.		15° 16′ E.
	30° 45′ N.		20° 00′ E.
D. Lat.	10° 30′ N.	D. Long.	4° 44′ E.
	60		60
	630		284



Construct a diagram to represent the problem and enter the above minute figures upon it.

Since neither of the two latitudes given is the equatorial latitude, but the D. Long. does represent the equatorial measurement, it will be clear that the departure will be equivalent to the mean of the two latitudes. Therefore the first step is to average out the *middle latitude*.

$$\begin{array}{r} 20^\circ\ 15' \\ 30^\circ\ 45' \\ 2 \mid \overline{51^\circ\ 00'} \\ 25^\circ\ 30' = \text{middle latitude.} \end{array}$$

Then Dep. = D. Long. × Cos 25° 30′

= 284 × Cos 25° 30′

From the table book :—

$$= 2.453318 \quad 9.955488$$

$$\text{Add} \quad 9.955488$$

$$2.408806$$

Extract from table book :—

(1) Therefore Departure is 2.408806 = 256.3.

Enter up on diagram.

Dep./D. Lat. or P/B = Tan θ. That is 256.3/630 = Tan θ.

$$256.3/630 = 2.408749$$

$$= 2.799341$$

$$9.609408$$

$$\text{Course} = \text{Log. Tan } \theta$$

$$= 9.609408$$

$$= 22^\circ\ 8'$$

(2) Therefore the Course is 22° 8′.

Hyp./Base = Dist./D. Lat. = Sec θ.

$$\text{Therefore Distance} = \text{D.Lat.} \times \text{Sec } \theta$$

$$= 630 \times \text{Sec } 22^\circ\ 8'$$

$$= 2.799341 \quad 10.033244$$

$$10.033244$$

$$2.832585 = 680.1.$$

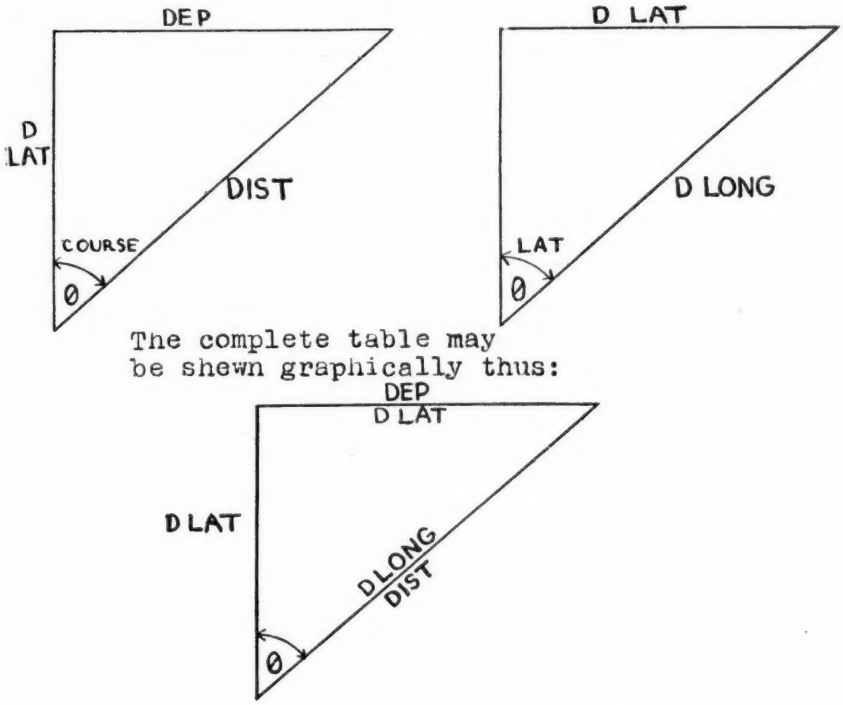
(3) Therefore the Distance is 680.1.

The Traverse Tables

For convenience in the solution of many of the problems connected with navigational calculations a series of tables known as the Traverse Tables may be utilised. The construction of these tables can clearly be understood from the following triangles :—

If the angle θ is the Course, then Distance, D. Lat. and Departure are given.

If the angle θ is the Latitude, then D. Lat. and D. Long. are given.



By means of the Traverse Tables we can cross-check the results obtained in the calculations made upon Departure, Course and Distance.

Take a Traverse Table Book. Check the problem set on page 326.

Traverse Tables.

Page.	Column.		Column.	
105	D. Long.	284	D. Lat.	257.4
99	D. Lat.	63	Dep.	25.5

At page top, page 99, is found 22° and in the column of distance the figure 68. Since the D. Lat. was divided by 10 for convenience, multiply the figure extracted by 10. $68 \times 10 = 680$.

Results obtained by the use of the Traverse Tables are sufficiently accurate for the purposes of navigation. For instance,

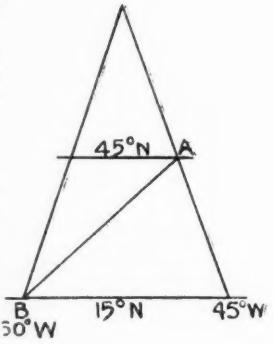
Dept. by calculation ... = 256.3
Dep. by tables ... = 257.4
Distance by calculation = 680.1
,, tables ... = 680

Direction of the Course

It must be remembered that in these calculations we have folded the circle so that all quadrants fall into the top right hand quadrant. Therefore when the course is laid in any quadrant which is not the top right hand quadrant it is

necessary to add to the course the angle which was deducted by folding the circle. In the case we have just considered the course fell in the natural right top quadrant. To find which quadrant the course lies in the easiest method is to draw a sketch of the course laid down, thus:—

From A in 45° N. Lat. and 45° W. Long.
To B in 15° N. Lat. and 60° W. Long.

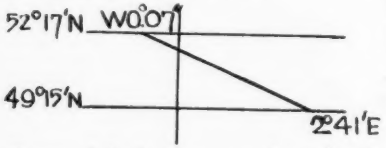


From sketch we see at once that the direction is south and west. Therefore we have folded the third quadrant into the top right hand quadrant. Thus we must add 180° to the course result to obtain the aircraft's course. When the course, considered from the centre of the circle, falls into the second quadrant add 90°; in the third quadrant add 180°; in the fourth quadrant add 270°.

Find the course and distance from Croydon to Paris.

Croydon Lat.	52° 17′ N.	Long. 0° 07′ W.
Paris	49° 15′ N.	2° 41′ E.

Sketch of Course.



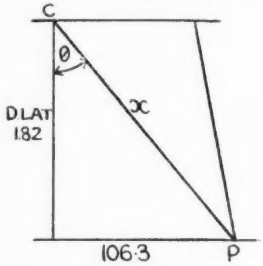
D. Lat.	*D. Long.*	*Note.*
3° 02′	2° 48′	With like signs subtract, with unlike signs add. Long. signs are unlike.
60	60	
182′ S.	168′ E.	

Course falls in the second quadrant.

Obtain Mid Lat.

52° 17′ N.
49° 15′ N.
2 | 101° 32′
50° 46′ Mid Lat.

Sketch of Result of Stage 1.



(*Stage* 1.)

$$\frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Mid Lat.}$$

Dep. = D. Long. × Cos Mid. Lat.
= 168 × Cos 50° 46′
= 2.225309 9.801047
9.801047

2.026356 = 106.3
Departure = 106.3

(*Stage* 2.)

Dep./D. Lat. or P/B = Tan θ or alternatively D. Lat./Dep. or B.P. = Cot θ.

106.3/182 = 2.026356 / 2.260071 = 9.766285

182/106.3 = 2.260071 / 2.026356 = 10.233715

Course.
30° 16½′
90°

120° 16½′ *Course in second Quadrant.*

(*Stage* 3.)

Dist./D. Lat. or H/B = Sec θ or alternatively X/Dep. or H.P = Cosec θ.

$H = B \times \text{Sec } \theta$ $\quad$ $X = \text{Cosec P}$

$= 182 \times \text{Sec } 30^\circ\ 16\frac{1}{2}'$ $\quad$ $30^\circ\ 16\frac{1}{2}'$ $\quad$ 106.3

$= 2.260071 \quad 10.063680$

10.063680

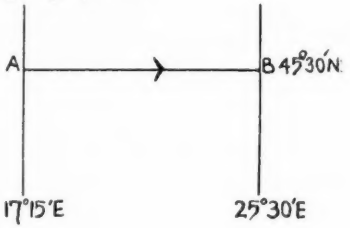
$12.323751 = 210.7$

Distance 210.7.

Parallel Sailing

Find the Course and Distance from A in Lat. 45° 30′ N.
Long. 17° 15′ E.
to B in Lat. 45° 30′ N.
Long. 25° 30′ E.

45° 30′ N.	17° 15′ E.
45° 30′ N.	25° 30′ E.
00° 00′	8° 15′
	60
	495′



(1) Course due East = 90°

(2) Dep./D. Long = Cos Lat.

$X = \text{D. Long.} \times \text{Cos Lat.}$

$495 \times \text{Cos } 45^\circ\ 30'\ \text{N.}$

$= 2.694605 \quad 9.845662$

9.845662

Log. of Dist. $2.540267 = 346.9$

Therefore Distance = 346.9.

Conversions

Note.—All linear measurements by trigonometrical calculation are solved in minutes, which we have seen are equivalent to nautical miles. Therefore, if statute miles or kilometres are required it is necessary to apply the conversions to obtain the measurement in these units. Angular measurements are obtained in degrees and minutes. If required in Grads and Kilometres the conversions shown on page 324 should be made.

Statute Miles to Nautical Miles and Nautical Miles to Statute Miles.

$$\frac{6{,}080 \text{ ft.}}{5{,}280 \text{ ft.}} = 1.15 \text{ statute miles to 1 nautical mile.}$$

$$\frac{5{,}280 \text{ ft.}}{6{,}080 \text{ ft.}} = .8684 \text{ nautical miles to statute miles.}$$

$$\frac{6{,}080 \text{ ft.}}{3{,}280 \text{ ft.}} = 1.854 \text{ kilometres to nautical miles.}$$

$$\frac{3{,}280 \text{ ft.}}{6{,}080 \text{ ft.}} = .54 \text{ nautical miles to kilometres.}$$

$$\frac{3{,}280 \text{ ft.}}{5{,}280 \text{ ft.}} = .62 \text{ statute miles to kilometres.}$$

$$\frac{5{,}280 \text{ ft.}}{3{,}280 \text{ ft.}} = 1.61 \text{ kilometres to statute miles.}$$

In what latitude will the relation of Departure to D. Long. be as 1 is to 2 (sometimes written 1 : 2)?

$$\tfrac{1}{2} = \frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Lat.} \quad \therefore \tfrac{1}{2} = \text{Cos Lat.}$$

$$0.000000$$
$$0.301030$$
$$\overline{9.698970} = 60°.$$

The problem may be also solved thus:—

$$\tfrac{2}{1} = \frac{\text{D. Long.}}{\text{Dep.}} = \text{Sec Lat.}$$

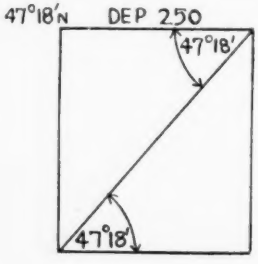
$$0.301030$$
$$0.000000$$
$$\overline{10.301030} = 60°.$$

In latitude 47° 50′ N. you fly 200 miles due west. What is the D. Long.?

$$\frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Lat.} \quad \text{Therefore D. Long.} = \frac{\text{Dep.}}{\text{Cos Lat.}} = \frac{200}{47° \ 50' \text{ N.}} =$$

$$2.301030$$
$$9.826910$$
$$\overline{2.474120} = 298' = 4° \ 58'.$$

You fly from A in Lat. 47° N., Long. 18° W. and the Track is 90° True, Distance 250 Nautical Miles. What is the Lat. and Long. of the point of arrival?



A 47° N., 18° W., to 250 miles E.

$$\frac{\text{Dep.}}{\text{D. Long}} = \text{Cos Lat.}$$

$$\text{D. Long.} = \frac{\text{Dep.}}{\text{Cos Lat.}} = \frac{250}{\text{Cos } 47° \ 18'}$$

$$2.397940$$
$$9.833783$$
$$\overline{2.564157} = 366.5' = 6° \ 6'.5$$

Long. at start of flight 18° 00′ W.
D. Long. of flight ... 6° 06½′

Long. of arrival ... 11° 53½′ W.
Latitude of arrival ... 47° 00′ N.

Check by Traverse Tables (page 142) 47° at bottom of page, Dep. 250, D. Long. 367′.

Find the course and distance

From A in Lat. 45° 17′ N. Long. 15° 18′ E.
To B ,, 47° 23′ N. ,, 18° 12′ E.
D. Lat. 2° 06′ N. D. Long. 2° 54′ E.
= 126′ = 174′
Mid Lat. 46° 20′

(1)

$\frac{\text{Dep}}{\text{D Long}} = \text{Cos Mid Lat}$

Dep = D Long x Cos Mid Lat

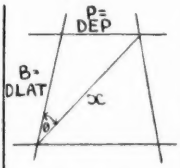
= 174 x Cos Mid Lat

= 174 x Cos 46° 20'

= 2.240549
9.839140
2.079689

= 120.1

(2)



$\frac{P}{B} = \text{Tan } \theta$

$\frac{\text{Dep}}{\text{D Lat}} = \text{Tan } \theta$

$\frac{120.1}{126} =$

2.079689
2.100370
9.979319

N43° 38'E
or
043° 38'

(3)

$\frac{\text{Dist}}{\text{D Lat}} = \text{Sec } \theta$

Dist = D Lat x Sec θ

= 126 x Sec 43° 38'

2.100370
10.140399
12.240769

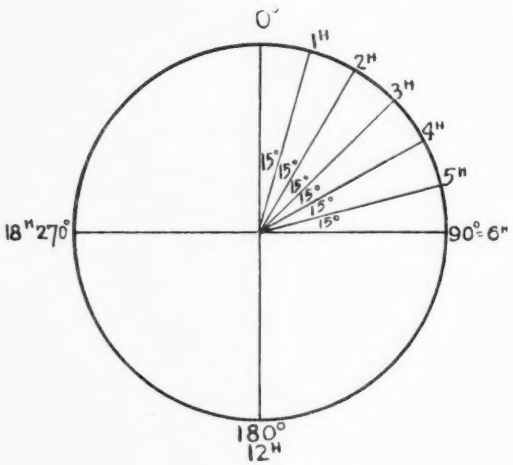
= 174.2

Course = N. 43° 38′ E. or 043° 38′.
Distance = 174.2 Nautical Miles.

The Time Angle

Since the earth rotates (from West to East) once each 24 hours it is clear that there will be a difference between the time at the Prime Meridian, *i.e.*, Greenwich Mean Time and the Local Time at any point on the earth's surface not on the Prime Meridian. The difference bears a direct relation to the division of the circle into degrees and is known as the Local Hour Angle, and is expressed in time as the Local Mean Time.

The theoretical consideration is as follows:—



360 Degrees
24 Hours
Therefore 15° = 1 Hour.
The conversion therefore is
(90 × 4) ÷ 60.
90° = 6 Hours.

Convert 187° 49′ 00″ into Time.

187° 49′ 00″

60 | 751 16 | 4

12 Hours 31 Minutes 16 Seconds.

Convert 12 Hours 31 Minutes 16 Seconds into Time Angle.

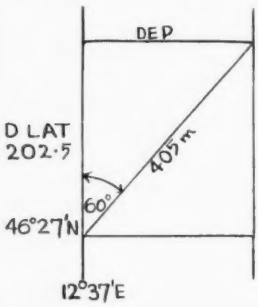
12 Hours 31 Mins. 16 Secs.

60

4 | 751 16

187° 49″

You leave an aerodrome in Latitude 46° 27′ N., Long. 12° 37′ E., at 14.35 Hours Local Mean Time, and fly on a course 060° True, Distance 405 nautical miles to a point X. Assuming the ground speed to be constant at 75 knots, what will be the Local Mean Time of arrival at X?



Lat. left 46° 27′ N., Long. left 12° 37′ E.

Turn up Traverse Tables, page 116, with 60° at bottom of page and at 405 Dist., find:—

Dist.	*Dep.*	*D. Lat.*
405	350.7	202.5

Lat. left	...	46° 27′ N.
D. Lat.	...	3° 22′ N.
Lat. of arrival		49° 59′ N.

Latitude left ...	46° 27′
Latitude of arrival	49° 59′
	96° 26′
Therefore Mid. Lat.	48° 13′

$$\left(\frac{\text{Dep.}}{\text{D. Long.}} = \text{Cos Mid. Lat.}\right) = \left(\frac{350.7}{x} = \text{Cos } 48^\circ\ 13'\right)$$

$$x = \frac{350.7}{\text{Cos } 48^\circ\ 13'} \quad \begin{matrix} 2.544936 \\ 9.823680 \end{matrix}$$

$$2.721256 = 526.3$$

$$\frac{526.3}{60} = 8^\circ\ 46'\ 18''.$$

Therefore Longitude of Arrival $= 21^\circ\ 23'$.

405 miles flown at 75 K. ... ... = 5 hours 24 minutes
Time of departure ... ... = 14 ,, 35 ,,
Sum time of change of longitude

$$\begin{array}{r|l} & 8^\circ\ 46' \\ & 4 \\ 60 & 35\quad 4 \end{array}$$

$0^{H}\ 35'\ 04''$ = 35 ,,

20 hours 34 minutes

Therefore local mean time of arrival will be 20 hours 34 minutes.

Discussion

The Chairman: The paper was crammed with knowledge and was written in a most refreshing style. To him it was particularly refreshing; a month ago he had had no idea that he would be able to listen to any of the Society's lectures this year, and when one became so thoroughly out of touch with the practical side of things as one did when one was dealing only with the A.B.C. of flying, it was really refreshing to hear a lecture such as Captain Macmillan had delivered. He recalled that one of his earliest encounters with Captain Macmillan had occurred about ten years ago, when he had been called to a conference very early on a Sunday morning. At that time Captain Macmillan had just returned from an attempt to fly round the world, which had ended by his sitting on the upturned floats of his machine for 59 hours in the Bay of Bengal. Preparations were then being made for another attempt, and he (the Chairman) had been invited to join the expedition, the job offered him being to command a ship which was to go round the world dumping petrol and supplies. He added, however, that somebody else did that job.

He had been impressed by the enormous change which had taken place in air transport during the last few years. Until quite recently he had not seen the new types of passenger aircraft, and to fly on the air routes now, after an absence from the country of only two or three years, was an absolute revelation, and a revolution from the passengers' point of view. He had been permitted to go into the cockpit and to renew his acquaintance with piloting methods, and he had been impressed by the complete contrast between the haphazard way in which air transport was originally operated and the methodical manner in which it is operated to-day. That applied particularly to navigation.

In asking Captain Macmillan to deal further with his point with regard to carrying photographs of mountain ranges to aid in the identification of peaks, the Chairman suggested that one might be very badly led astray thereby, for the aspect of a mountain range changed continually. Both the shape of individual peaks and their relative positions changed with the height at which one was flying, changed constantly with one's position, and changed very considerably with the state of the clouds. A cloud might be situated between two parts of a complex range, obscuring part of it so that one saw apparently

an entirely different thing from that shown in the photograph, and it seemed to him that the number of photographs that it would be necessary to carry would be so enormous that they would be of very little practical value.

He was glad Captain Macmillan had emphasised one of the important elementary principles, *i.e.*, the principle of holding to one's course when in doubt. It was a principle which all navigation instructors emphasised.

Again, he asked that Captain Macmillan would say more about his suggestion for a Mercator projection for the polar regions. One would get a chart which would not look the same as the ordinary Mercator chart. The idea was interesting, but it was not clear how it would be worked out.

Finally, Captain Macmillan's reference to eight dimensions held out a terrifying prospect. They were just beginning to think in terms of four dimensions, while three had been sufficient up to the present. However, when one examined the matter, one would find that some of the eight dimensions mentioned were compounds of the three or four with which one ordinarily dealt.

Mr. GORDON ENGLAND (*Member of Council*): He would like first of all to express, on behalf of the meeting, a hearty welcome to Mr. Tymms and assured him how grateful they all were that he should preside over the meeting.

After commenting upon the wonderful progress which had been made with regard to navigation, Mr. Gordon England said that he, too, was extremely impressed by Captain Macmillan's reference to an eight-dimensional condition, and he could not help thinking of the wonderful opportunity it offered to the ingenious-minded of to-day in coping with that condition. Captain Macmillan's paper had been most inspiring, and had indicated how very much scope was still available in the improvement of the technique of navigation. Those who were keenly interested in the development of navigation under all conditions were looking forward to a solution of that very difficult problem—which Captain Macmillan might have given a little more attention to in the paper—the problem of landing under conditions of obscurity. Perhaps in time Captain Macmillan would give some indication of how that problem was going to be tackled. In the paper he had given just a fleeting idea and had then—perhaps because of his great skill and experience in this matter—hastily proceeded to more safe territory.

Mr. C. B. COLLINS (who is in charge of Navigation in the Civil Aviation Department of the Air Ministry): He would like first to refer to the question of the constant bearing course. Captain Macmillan had rather left the impression, in citing the case of the Atlantic crossing, that invariably one obtained a course lying between the rhumb line and the great circle, with a consequent saving of distance. A certain amount of caution was necessary, however, in regard to a constant bearing course, because in particular regions the variation might change in such a way that the constant bearing course would not lie between the rhumb line and the great circle, but might even come outside the rhumb line and might be definitely longer. That was a minor point, but it was a matter of studying how the variation changed along the particular course one wished to follow.

Mr. Collins regretted that Captain Macmillan had not laid more emphasis upon the ease of carrying out astronomical navigation in the air. In this connection he called attention to an article by Major R. E. Penny, O.B.E., in the 1933 *Air Annual*, in which the future of the big flying boat was shown to be very bright. He personally agreed that the flying boat type of air transport would develop, and if that was so, they would have to think rather differently from what they had done in the past in regard to the requirements of air navigation. At the moment they were rather inclined to limit their views of air navigation to what was required for overland routes, but when the flying boat really developed and became capable of long ranges, then the present methods of dead reckoning and wireless direction finding (he was thinking more particu-

larly of trans-Atlantic and similar routes) were likely to break down. He doubted, for example, that the range of direction finding as they conceived it at the moment was sufficiently adequate to meet the exacting requirements of air navigation for long flights. They would therefore endeavour to regard the subject of astronomical navigation more seriously. The Americans were studying the problem in great detail. Reference had been made by Captain Macmillan to the tables published by Lieut.-Commander J. Y. Dreisonstok, of the United States Navy, but since those tables were published, some years ago, the Americans had prepared a further book of tables by J. E. Gingrich. Mr. Everett had added to his general analysis of tables, published in the Society's Journal, and had shown that these particular tables were worthy of consideration. Mr. Collins also regretted that Captain Macmillan had rather dismissed the possibilities of the Bygrave slide rule as something which should come after the consideration of tables. The Bygrave slide rule, however, *in the hands of those accustomed to use it*, could perform the same function as tables in probably less time, and certainly to the same order of accuracy. The question of the use of the Bygrave slide rule as against the use of tables was largely one of personal preference, but he did not see why an individual accustomed to using the ordinary common slide rule with confidence should not be able to use the Bygrave slide rule, with all its advantages.

The reference made by Captain Macmillan to the activities of the Fleet Air arm were fully justified, and Mr. Collins agreed with him entirely as to the admirable navigational performances of those serving therein. It was surprising how tiny a speck on the ocean an aircraft carrier could appear when one had to return to it after a sea reconnaissance.

With regard to the Mercator projection for the polar regions, he shared with the Chairman some perplexity as to the appearance of the projection when applied to those regions. The meridians and parallels would seemingly be reversed. The International Commission for Air Navigation had recently decided to standardise a map for the polar regions on the stereographic projection, which would fit as a sort of polar cap on to a basic Mercator projection (on a scale of 1 : 10,000,000 at the equator) in latitude 72° N. and S. respectively. Each of the polar caps would comprise four sheets.

Finally, with regard to marginal photographs on maps as against the conventional signs, Mr. Collins suggested that an ideal solution would be to have a film of a cross-country flight which would move at the appropriate ground speed and so correspond to the actual ground over which one was flying. That, of course, was impossible, and in order to achieve neatness and conciseness in flying maps, they had to rely upon conventional signs. But he did think that it would be of advantage if on existing flying maps it would be possible to put in the margins pictures more or less on the lines of the Admiralty charts and sailing directions, in which important landfalls were given. He asked for expressions of pilots' opinions as to the value of such marginal insets.

Commander SHARMAN (of the Naval Air Division): From the sea aspect the word " wind " should be written in capital letters. Before leaving a carrier, one could, by using the ordinary meteorological balloon, ascertain the strength and direction of the wind at any height. By examining a series of weather maps, one can see that over a distance of 100 to 150 miles the wind does not always remain constant. If an aircraft took off for a four-hour patrol from a carrier steaming at 15 knots, and if during that time the aircraft went out and back 100 miles, then the aircraft would cover a large area of sea and large variations in the strength and direction of the wind might be expected. One's ability to navigate back to the carrier depended upon knowing the strength and direction of the wind and it would therefore be necessary to check the wind every half hour or twenty minutes.

A thermometer was useful, because if the temperature changed suddenly one could be quite certain that there had been a change of wind. Commander Sharman recalled an occasion when the safe return of a certain aircraft to the carrier was entirely due to the observer noting this fact.

With regard to visibility at sea, it was always assumed that at a height one could see better. On the average, however, the visibility from the air was about 50 per cent. better than on the surface. At sea it is often misty or slightly hazy; sky, sea and ships then appear much the same colour, added to which there is no silhouette when looking down on a ship.

Commander Sharman, commenting on the references made to the use of wireless for direction finding at sea, said that it was used, but it had two disadvantages. One was that the instrument was liable to break down, and inasmuch as the lives of the crew depended upon getting back to the aircraft carrier, it was as well therefore that one of the crew should be capable of navigating. Secondly, probably it would be impossible to use wireless freely in war time, because of the danger of giving away to the enemy the position of the ship.

Captain FERGUSON: He criticised Captain Macmillan's statement that "theoretical navigation is simple enough." If the word "theoretical" included preparation on the ground before starting off, then he did not consider that it was simple enough. One of his greatest difficulties was to get people to understand the simple elementary theoretical side of navigation. If only they would understand it and get to know it they would not get lost. Captain Macmillan had said that if only they kept to their compass course they would not get lost; but they did get lost, because they did not trust their theory.

Astronomical navigation, in his view, was more or less freak navigation, and he could not imagine Imperial Airways pilots in the future taking out a sextant and getting a shot at the sun, when they could, by the aid of wireless, ascertain their position, even in the Atlantic—though he did not suppose that the latter could be done yet. He did not see, however, why wireless should not develop so that pilots could ascertain their position at any distance, if there were more intermediate stations, and if an international Morse code—not a language—was used. The same argument applied to finding one's way back to a ship at sea. Why should not an aircraft carrier have wireless directional equipment, such as was to be installed at Croydon, in order that the aeroplanes might find their way back to it?

The importance of drift, he suggested, might have been rather over stressed. With a 25-miles-an-hour wind at right angles to the course of an aircraft, the drift depended entirely on the air speed. With an air speed of 60 miles per hour and a 25-miles-an-hour wind at right angles, the angle of drift was 25 deg.; with an air speed of about 80 miles per hour the angle of drift was about 18 deg.; at an air speed of 100 miles per hour the angle of drift would be about 15 deg.; and at an air speed of 180 miles per hour the angle of drift would be about 8 deg. Thus, the greater the air speed, the less drift entered into the matter. They were reaching commercial speeds of 180 miles per hour, which in the future would be exceeded, and it was only with the slower machines that they had to consider to any great extent the question of drift.

Captain Ferguson did not agree that a height indicator, which would indicate the height above the ground, was so very important, and he did not quite understand the object of knowing that height. What he wanted to know was the height at which he should fly in order to clear anything in front of him. For example, if he were flying in more or less fog from Heston to Hatfield, he had to bear in mind two possible obstructions—Harrow-on-the-Hill and the wireless masts near Hatfield. If he had a height indicator and knew his height above ground, he might be able to recognise when he was getting to the hill at Harrow, but no instrument could indicate his height above the wireless masts near

Hatfield, and he might very well bump into them. Therefore, he wanted to know his height in relation to obstructions in front of him, and not so much his height above the ground beneath him. Miss Honor Rendall had designed a height indicator which warned the pilot of change in barometric pressure, and he believed it would help to a certain extent. Again, he did not appreciate the importance of knowing accurately one's air speed at all heights. One might have the opportunity of marking off, on the bearing flown, the air speed at suitable intervals, and draw in the wind direction and velocity at the end of each time interval. For ordinary every-day navigation, however, it was more important to know the ground speed, and he considered that an instrument which would indicate instantly one's ground speed would be of more use than knowing correct air speed. Recently he had seen an instrument which represented an entirely new departure. It was yet in its initial stages, but with it one could ascertain ground speed in a few seconds by looking at any object on the ground.

Finally, Captain Ferguson urged that internationally they should insist upon people knowing more about elementary air pilotage, rather than that they should learn about lights and signals, black balls and shapes.

Captain R. H. STOCKEN: The addition of pictures to the sides of maps reminded him that some years ago the Spanish Aero Club had produced a map covering the area from San Sebastian to Madrid, and on the sides of the map there were silhouettes of the various ranges. These were quite useful, the only trouble being that the map itself was inaccurate as regards detail.

Mr. A. J. HUGHES: He regarded the paper as being remarkable in some respects, and especially because it would induce in pilots some confidence in the instruments they used. Most papers dealing with navigation were somewhat frantic. One was published in *Flight* a week ago, and on reading it one might think the inexactitudes were such that the compass was not fit to be used. On the other hand, one of the strongest points made by Captain Macmillan was that one could have confidence in the compass. One often felt that an air pilot would think more of his compass and of hanging on to his course if he considered what he would do if he were at sea; under those circumstances he would not think of turning from his course, but would hang on until he sighted land. Recently Mr. Hughes had had the pleasure of travelling across the North Sea from Grimsby to Bergen in a trawler. The navigator had not thought of changing the compass course, but had steered north-east and had hung on to his course, although the weather was extremely bad. That was the only possible way. He appreciated, of course, that there were very great disadvantages in the use of the compass; some people suggested that it should be eradicated altogether, but it had not yet been dispensed with at sea, in spite of the gibes. This country had the honour of producing the finest compass system in the world; the Royal Air Force compasses were known throughout the world as being the safest.

The effect of northerly turning error should be treated as other physical factors, such as a cloudburst or a cyclone, which were dealt with by the sailor with very great caution, and the air pilot must be constantly alive to the effect of northerly turn in using his compass. Mr. Hughes emphasised the importance of a rear bearing from the point of departure when flying. Mr. Gatty, navigator for Round the World Flight, had always considered that one of the most important factors in safe navigation was to take a rear bearing and observe the exact point of departure.

Discussing height indicators, Mr. Hughes recalled some tests made in the R.101 to ascertain height over both land and sea, and said that no doubt they should have in the future a height indicator which would operate by means of acoustic vibration. He was afraid, however, that it would be a very long time before we should have an instrument to indicate the height of any obstruction in front of an aircraft.

Captain COUPLAND: He agreed that the whole question of navigation was to trust the compass and to stick to one's course. The compass did behave in a funny manner sometimes, but if people really would stick to their compasses and carry on they would be more likely to accomplish their flights successfully. He thanked Captain Macmillan for a most instructive lecture.

Mr. P. F. EVERITT: A reference was made to a short paper he had put forward some time ago on navigation tables—in which paper he had only gone as far as to use tables that were available to Squadron Leader Johnson. Since that time new tables had been issued in the United States by Lieut. John E. Gingrich, U.S. Navy. These latter were reviewed in the Aeronautical Society's Journal within the last twelve months, so that he need not say more about them at the moment, except that he had a copy with him which he would be pleased to show to anyone interested.

Dr. A. P. THURSTON: He drew attention to a most excellent instrument designed by Flight Lieut. Stainforth, known as a flight indicator, which enabled one to set one's course accurately from the beginning.

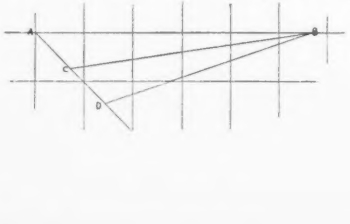
A SPEAKER: How far up can chronometers be used in aircraft, and does the vibration of the aircraft upset them?

Mr. SCOTT-HALL (Martlesham Heath): He was interested to note the stress that had been laid upon the value of illustrations of the contours as an aid to finding one's position in mountainous regions, because Admiral Byrd, in his book, had stated that on the south polar flight he had taken with him all the sketches prepared by previous explorers and surveyors of the mountains surrounding the central plateau, but that he found them very difficult to identify. Admiral Byrd had emphasised, therefore, that the observer using such projections should know very accurately indeed from what aspects they had been prepared.

(*Communicated*).—He suggested that the use of the word "dimension" in the sense that the author had used it, was rather misleading, since it might be confused with the common interpretation of the term as used in physical science. In the discussion it apparently had been already! He suggested substituting the word "unknown," a mathematical term conveying more forcibly the pilot's difficulties.

Captain G. F. MEAGER (late First Officer and Assistant Navigator, R.100): He would like to submit, in regard to the lecturer's statement that it is fundamental that the course should never be altered unless the pilot knows his position, that this is right only up to a point. If one were flying above cloud, or in fog, then he agreed it is the only thing to do, but if the ground is in view, he would say it is much more fundamental to keep a constant check on one's drift, and vary one's course according as the drift is more or less than that originally anticipated or worked out. He was of the opinion that Cecil Grace lost his life by maintaining his original erroneous course too long.

Then later, the statement that turning back and proceeding on a reciprocal bearing would take the pilot back approximately to his point of departure, also needs qualifying, as this is only likely to be of any use if there were little or no wind. If there were a wind of any force at all, by flying on a reciprocal bearing, the pilot would in all probability find himself in a worse plight than before he turned. This may perhaps be clearer from the following diagram in which it is assumed that the pilot wishes to proceed along the line AB in a machine whose air speed is 100 m.p.h., with a N.W. wind of, say, 20 m.p.h.



Omitting compass error, it will be seen that the course to steer is CB, approximately 82°. If he turns round and steers the reciprocal of this, *i.e.*, 262°, his machine will fly heading in this direction, but will make good over the ground on the return journey, the course BD, which as one can see is hardly approximate to line AB, and the longer he continues on this course the further from his point of departure will he become.

The constant bearing course certainly sounds a reasonable method for present-day machines engaged in flights across the Atlantic or other long distances over the sea or over unsurveyed land, but for airships and large flying boats, which can carry a navigator, it is doubtful whether such a method would be used. In fact, it is probable that neither a great circle, a direct rhumb line, nor a constant bearing course will be strictly conformed to. Courses will be laid as much as possible in conformity with the weather chart so as to take advantage of any helping wind, or at any rate to minimise its adverse effects. They experienced two typical examples of this during the Canadian flight in R.100. On the outward flight they made a course round the north of Ireland with the result that they received the help of a N.E. wind on the first part of the ocean journey. At the same time a westerly gale was blowing off the south of Ireland. Prior to leaving Montreal for the return journey, the weather reports and charts indicated the prospect of westerly winds all the way across the Atlantic. However, six hours after passing Belle Isle, they were bucking into a north-easterly wind of 35 knots, which had not been anticipated or forecasted. In order to minimise the retarding effect of this, and also in the hope of getting into an area of more favourable wind, the airship's course was altered to S.E. The drift was checked as frequently as possible through breaks in the clouds, and after about four hours the wind was found to back suddenly to the westward, and a little later to the southward. It might also be of interest to mention the sudden sharp rise in temperature which was experienced at the time of the sudden backing of the wind. For some minutes the airship was in a very disturbed area, and the coxswain found steering difficult.

While on the subject of weather, might he draw attention to an omission from the lecture of what, to his mind, is one of the most important hazards in long distance flying; he referred to difference in atmospheric pressure between the point of departure and over the route to be flown. He thought Captain Macmillan did mention, when advocating the necessity of a "height over the ground indicator," that an aneroid could be as much as 1,500 feet in error. He believed that many of the attempted flights across the Atlantic which have ended in disaster, have been caused by neglecting to study the weather charts showing the distribution of pressure over the wide expanse to be covered. With the preponderance of low cloud that is experienced over the Atlantic, it seems highly probable that many of the flights have ended by the machines having been flown straight into the sea, while the pilots thought from their altimeter reading that they were some hundreds of feet up. It is possible they may have been flying over the top of the clouds and then decided to come down through them to get some idea of their drift, or perhaps to see if any shipping were near, and while still thinking themselves some hundreds of feet above the sea by the aneroid reading, have precipitated themselves into the water.

After one of the Atlantic attempts had ended in disaster, he worked out the barometer difference for that day between England and a deep depression out on the Atlantic—it was roughly 30 mb., which, taken at 30ft. to the mb. (27 is more correct) makes the aneroid error of the order of 900 feet. In other words, the aneroid, set in England before leaving the ground, would, when the machine reached the area of the centre of low pressure, read 900 feet and the machine would be in the water. (This is apart from any lag in the aneroid reading after flying at a height for some time.)

He might add that at the same time as the above, a machine could have left

Germany and flown into the sea at the centre of the depression with as much as 2,000 feet showing on the altimeter.

Although he had not worked it out, it is quite possible that neglect to study pressure differences likely to be met with on their route, was the reason the R.A.F. long distance attempt ended by flying into the Atlas Mountains.

Whether the above can be said to come within the scope of " navigation," it is hard to say, but it certainly should come within the scope of the " navigator " and of " airmanship."

As regards navigation methods and aids during the flights across the Atlantic and back in R.100, they found the " Hughes periscopic drift sight " a wonderful asset. By taking the drift on two courses only (*i.e.*, the course steered and another up into the wind at about 40° to it) this instrument gave the strength and direction of the wind. The course to steer could also be worked out with it. Another advantage was that there was no necessity to lean out into the air stream when taking readings. Over the sea, during daylight, the drift was taken from the tops of breaking waves when clearly defined, or failing this, a small aluminium dust bomb was dropped. These gave an excellent mark in the water. By night they used a calcium phosphide flare which automatically lighted when thrown into the sea and remained alight for some considerable time. The heights from which these markers were dropped was 1,500 to 2,000 feet. It may be of interest to the Aeronautical Society, that the drift sight mentioned above is based on the invention of one of the Society's Vice-Presidents, Mr. Wimperis.

D.R. positions were checked by wireless bearings given them by steamships on the route, and whenever possible by astronomical observations. Two independent sets of sights were usually taken—Squadron Leader Johnston used a Mark VII Booth bubble sextant, and he used a Mark V. These sights were most useful in checking the D.R. when no ships were in the neighbourhood. On one occasion both their intercepts came to over 60 miles. When laid off on the chart, allowing for the difference in time between the two sets of sights, they gave an identical position line which put them 60 miles further north than they thought they were and shows how easy it is to get off one's course if one is unable to obtain any idea of one's drift. Another very useful astronomical sight was one taken when they were flying above a thick bank of fog in the Straits of Belle Isle. Good sights of the Pole Star and of Altair within a few minutes of each other, gave a cut which placed them nine miles further south than they thought they were.

The above examples serve to show that, though stellar observations will be less and less necessary in the future as W.T. D.F. improves and becomes more accurate over long distances and in all weather conditions, the pilot or navigator should know how to take an observation of a heavenly body and be able to work it out in case his W.T. fails, or possibly in the event of his having to make a forced landing in sparsely populated country.

As regards their methods of working up their sights, Johnston used Goodwin's " Alpha, Beta, Gamma " tables, while he used the Marq St. Hilaire method, using Inman's tables.

The " Bygrave " slide rule was not used in R.100, because though it is certainly a quick method when one is used to it, yet by whichever system the sight is worked, there is no getting away from having to put pencil to paper in working out the hour angle. This being so, it is very little extra labour to put the other working down on paper as well (preferably in a book) so that a record is kept.

He doubted whether great circle flying, either by airship or by aeroplane, will ever be very much indulged in, although they have the classic example of Lindbergh's flight across the Atlantic when he worked out his great circle track beforehand, and altered his course to conform to it at certain intervals during

the flight. Continuously changing weather conditions are the chief obstacle to great circle flying, apart from the bother of having to change course at intervals, and the difficulty of knowing for certain whether one has reached the correct spot at which to alter course.

It would, he thought, have been interesting to prospective students of navigation if Captain Macmillan had explained the derivation of " Mercator " from " Kauffman " as being the Latin equivalent of that name, which means " merchant " in German.

With regard to the last paragraph but one of Captain Macmillan's most interesting lecture on a very difficult subject, he expected it would interest him to know that a very efficient " height over the ground " indicator is installed in the " Graf Zeppelin." This is the " Behm " echo sounding device. It is always used to set the aneroid correctly before landing. He could not say if it is used continuously when flying over unknown country as he had never been on a flight of this description in that airship. One of her officers told him, however, that the two instruments they most valued in the airship were the gyro compass and the echo sounding device. He saw no reason why it should not be adapted for use in aeroplanes. It, of course, only indicates the distance to the earth immediately beneath the machine.

Reply to Discussion

Dealing with the suggestion that pictures of mountain ranges might not be of much help because the mountains might possibly be obscured by clouds, he pointed out that if the mountains were obscured even a map was not of much use. He had flown over a good many mountain ranges, and had generally found that the wilder the ranges the worse were the maps; they did not give the exact positions of prominent peaks, frequently they did not give heights correctly, and they gave very little information which was of use to the pilot to enable him to cross the range safely. Very often, when flying over mountain ranges, and especially the very high ones, the lower altitudes were obscured by cloud, but the peaks emerged through the top of the cloud-layer, so that a pilot would be able to take a check when he could not see the country below, provided he had accurate data with regard to the higher peaks. Contour gradients and information regarding the prevailing winds are also most valuable for trans-mountain flights to enable the pilot to estimate for up and down currents.

With regard to a chart for polar regions, it was his intention to have one made to illustrate what was in his mind, and if it were approved by the Secretary and Council of the Society he hoped it would be published in the Journal later. It would be a Mercator chart purely for use in the polar regions, but would not fit into the Mercator charts for the lower latitudes. His idea in suggesting such a chart arose from the possibility that before many years had passed shorter air routes might be taken between America and Europe and between Europe and Asia, via the north polar regions.

As to the suggestion that the eight dimensions he had referred to were not really eight, he said that if one considered the matter purely from the physical aspect that would be true. The aeroplane would then become a body in the universe dependent solely upon the laws of physical science and the result would be a crash. But a pilot flying in fog maintained the equilibrium of his aeroplane in spite of the laws of physics by means of instruments and to defy the laws of nature required eight mental balances, so that it was eight-dimensional so far as the pilot's mind was concerned.

With regard to landing in fog, in America they were using a means of landing which was the most likely to give accurate results at the moment, because it was based upon the correct way in which a pilot should approach to land his aircraft. It led him down a definite approach angle which was safe,

and provided he remained within a certain range of an electric beam and used a certain number of revolutions of the motor, his aircraft would not stall but would descend slowly. In actual use this method required the pilot to reach a position near the aerodrome by means of direction finding or otherwise, following which circling the aerodrome enabled him to pick up a radial beam. Following this beam down brought him to a safe height over the boundary of the aerodrome. When that point was reached a signal was given by sound or by light on the dashboard. The pilot had then merely to pull back the stick, shut off his engine and the plane landed itself. Although this method was satisfactory, it was very expensive and did not solve the difficulty of making intermediate landings, because one could not imagine the installation of the necessary expensive instruments at different places all over the country. It seemed to him that we must try to develop, if possible, a means of enabling the pilot to see through fog. Admittedly, that would be difficult, but it might not be impossible; even if a pilot could see only a little distance ahead it would be of very great help. Infra-red photography appeared to point the way towards a solution.

It was true, as Mr. Collins had said, that a constant bearing course did not always lie between the rhumb line and the great circle line, and the question of the course to be flown must be decided for each particular route. But to fly a great circle course required the pilot to do a fair amount of juggling on the way; a rhumb line necessitated corrections at different parts of the journey for changes in variation; if he did not make the change at the right moment the pilot might go very much farther out than the additional distance entailed by a constant bearing. On a constant bearing course the pilot had only one other factor to deal with, and that was drift. The faster the machine, the easier it was to fly a constant bearing course because the time and drift factor was reduced.

Astronomical navigation, strictly speaking, related only to long distance flying. For such flying it could not be ignored, though it could be dispensed with for short distance flights. It might be true that wireless direction finding was liable to break down. At the same time, by far the most dangerous part of any long distance flight—excluding weather or forced landing—was the making of the land fall; it was the guiding into safe harbourage at the end of a long cross-country flight which was important. As to the safety of the other part of any flight, a great deal must be laid to the credit of the manufacturers of the aircraft and the engines which made the flight possible.

Commenting on Captain Ferguson's criticism of the statement that theoretical navigation was simple enough, Captain Macmillan said he had wanted, in this paper, to go into a good deal of the theoretical side of the problem, but he had not sufficient space and time; information additional to that given in the paper, however, would be published in the Journal. Actually the theoretical side *was* simple enough; the difficulty was to secure the proper combination of theoretical knowledge and practical experience. The one without the other was of very little use in any walk of life, and the pure theorist was not always a practical man. It was necessary to know the theory and equally necessary to be able to apply it, and unless the pilot had a proper combination of theoretical and practical knowledge he would always find either the theory or the practice difficult, and invariably the one which he knew least about.

It was true that drift affected slower machines to a greater extent than faster machines, given equal lengths of route, but as non-stop routes became longer with the increasing speed of aircraft, the question of drift would always prove troublesome in navigation. Moreover, aircraft frequently have to fly in winds of much greater strength than the 25 m.p.h. quoted by Captain Ferguson.

It was extremely difficult to indicate the height of obstructions ahead, but if a pilot knew accurately his real height above a particular piece of ground and knew when he was over it, it was quite easy to work out in advance the distance ahead of a wireless mast, for instance. But when flying over unknown ground

it was very difficult to work out how much clearance he must have. There could quite easily be a variation of as much as 1,500ft. if one were without a true height indicator, and that constituted a danger, especially the real danger which arose when flying blind. Instruments which necessitated ground vision for their operation might well be fatal equipment to carry.

He agreed with Mr. Hughes' remarks concerning the difficulty associated with the compass, but every pilot must allow for it. He had mentioned the matter in connection with blind pilotage. Again, he had referred to the rear bearing on departure, in connection with ship aerodromes, and it applied equally to aircraft flying from ground aerodromes.

Chronometers always suffered from vibration, and when used on aircraft they should be carefully mounted. In view of the speed of aircraft to-day, one could travel rapidly from place to place, and by making use of the electric time signals which were given out and which could be picked up throughout the world from places within easy navigational reach, one could check the chronometer and find out how it stood.

He had not seen Admiral Byrd's projections of the Antarctic, but it seemed to him that in all probability several explorers had made sketches and projections, all of which were made on a different basis. In any case, in those regions the appearance of a place might alter from year to year, having regard to snowfall, glaciers, etc., and a picture taken in one year might not coincide with the appearance of the same place a year later. What we really wanted was a straight line chart. Routes across the Antarctic did not lead from anywhere to anywhere, so that they had no commercial value or application in the world of aviation to-day and could be ignored. The Arctic routes, however, had real significance.

In reply to Captain G. F. Meager's written contribution, it is certainly necessary for the pilot to make allowance for the drift component which he applied on his original course when he turns to fly back to his starting point on a reciprocal bearing. The reciprocal will only be a true reciprocal in conditions of still air, and may even then be affected by a change in deviation in the compass on the new course. But these allowances can be made rapidly by mental computation by any pilot of reasonable experience.

I understand that the crash of the R.A.F. long distance monoplane in the Atlas Mountains was the result of that rare occurrence, a faulty aneroid which stuck at the maximum height reached, thus giving the pilot and navigator the impression that they were flying much higher than they, in fact, were, since for some time they had been slowly losing height. This is all the more reason to press for a true height recorder (echo sounding device or otherwise), and I believe that such an apparatus is at present being developed for aircraft by Siemens and Halske in Germany.

The 553rd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Fourth Meeting, First Half, 68th Session

The Fourth Meeting of the first half of the 68th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, November 3rd, 1932, when a paper on "Civil Primary Training," by Major H. G. Travers, D.S.C., was read and discussed.

Colonel F. C. Shelmerdine (Director of Civil Aviation) presided.

The Chairman: Major Travers had been connected with flying since 1914, in which year he had joined the Beatty-Wright Flying School at Hendon. In the following year he had joined the Royal Naval Air Service, and later was transferred to the Royal Flying Corps. Towards the end of the war he was in charge of one of the early instrument flying schools, and had had something to do with aircraft weather reports after the war. Since early 1929 he had been instructing—for the Bristol Wessex Club, the Cinque Ports Flying Club at Lympne and the London Aeroplane Club, and is now chief instructor in the latter club.

CIVIL PRIMARY TRAINING

BY

H. G. TRAVERS, D.S.C.

Part I.

The views expressed are my own at the time of writing the paper and may or may not be shared by others. As any living thing such as aviation must be constantly growing and changing slightly, I expect to have to modify my opinions in the future.

Civil primary training should endeavour to train the whole able bodied civil population to use the air as their lawful occasions demand.

Historical

In the beginning there was no departmentalisation of flying. The pioneers designed, financed, built, flew, crashed and repaired their own aircraft. There was no official military aviation. New-comers visited the pioneers, bought machines and taught themselves as the true pioneers had done.

Quite early and long before the Admiralties and War Offices of the great nations could be induced to take any interest, some of the pioneer firms started schools of their own, where there customers could learn to fly.

Foremost among these were the Wright Brothers in America and the Farmans in France.

It is of very great interest to note here that the Wright Brothers had graduated from gliders, and that they fitted dual control to their first and later school machines; while the Farmans devised the other system under which the pupil was put alone to rolling practice, then hops, straight flights and finally circuits.

The English, influenced probably by the outstanding achievements of Blériot's first Channel crossing and the proximity of France, seem to have adopted the French method in the beginning and it was several years before Mr. Beatty opened a Wright School of Flying on Graham White's aerodrome at Hendon. Dual control was originally adopted in England to economise aircraft.

Much mud has been thrown at pre-Gosport instruction, but to obtain a just perspective we should divide the history of Flying Training into several periods. The first may be called the true pioneer era when all were groping in the dark. This ended about 1910 and was succeeded by the second period when those who had gained some rule-of-thumb knowledge imparted it to their pupils.

The military services were at that time represented in the flying schools by individual officers of vision who were learning there all that was then known about the handling of aircraft.

During the third period, 1912-1914, the military started schools of their own, but added nothing to the common fund of knowledge for many years.

It may interest admirers of super-aerobatics to be reminded that the Chute de Chevillard (a sort of stalled turn), the loop and the bunt were all first performed by civilians and for show purposes. Civilian schools did good work up to and after the outbreak of the German War.

Fourth Period. Although this is a paper on civil training, it is not out of place to say that the quality of flying training reached its lowest during the years 1914-1917. Most of the pre-war instructors had been called up, and replacements followed one another so rapidly that much valuable knowledge both in actual preliminary training and in cross-country flying was lost.

The Fifth Period was entirely military and is that of the much-needed Gosport reform. But, being devised to train war pilots, aerobatics were at a premium and cross-country flying at a discount. The sixth is also military and is that of the present day Central Flying School. Almost coincident with this period is the renewal of civil instruction which began in a small way at Brooklands under the late Colonel Henderson and at the five subsidised clubs—London, Bristol, Norfolk, Midland and Lancashire.

Present-day Training

I would like to suggest that for civil primary training we are now entering a seventh period, which may be described as Wittering sequence adapted to civil conditions.

The C.F.S. sequence is too well known to need repeating here, and so to a lesser degree is the C.F.S. sequence for blind flying. It is generally acknowledged to be the finest military flying training in the world. But when it is remembered that the civil schools have to deal not only with some young men in perfect physical and mental condition, but also with old men, busy business men and young women, the halt and the maimed and the very nearly blind, all of whom are paying their own good money to learn to fly and most of whose attendance is irregular, it will be sympathetically understood that the very excellent C.F.S. sequence must be modified for civil schools.

At the London Aeroplane Club we have done this by abbreviation of those paragraphs which do not apply to modern civil aircraft (aileron drag for example) and by spending more time on the separate use of the controls.

To many beginners the use of the feet to create a yawing movement is strange at first, so with the instructor working the stick and the throttle the pupil is drilled in rudder work on the ground and in the air at various throttle openings. He learns how to suffer the minimum of inconvenience from the bad forward view of to-day's tractor aircraft. Similarly, with the instructor working the throttle and rudder, he is drilled in use of the stick at all speeds and attitudes.

When he really knows what he is doing with the controls separately he is

allowed to use both together. The extra time spent on a thorough understanding of the use of the controls plus real care in insisting on a comfortable flying position and good helmet is well repaid in later stages.

By this method the pupil has been unconsciously taught to preserve an accurate attitude during the take-off and landing. " Operative " and " optical " landings begin during his early lessons. Taught this way, stalls, spins and loops seem natural. " Hacking round the aerodrome " has ceased. To avoid any chance of going stale, map reading and compass flying are given as weather permits. Fog and gales alone stop instruction. There is something to do all the time. The drill sergeant bullying and cursing of the pupil is a thing of the past.

Qualities of Instructor

Civil primary training nowadays calls for a type of instructor who has had to deal with a wide variety of human, and, if possible, of aircraft types. His own flying should be easy and unselfconscious. He must be able to analyse the movements of the aircraft while the pupil is apparently in sole charge, to fly the machine through the voice-pipe, to encourage a fluid swing of the controls and create an alert but happy state of mind in his pupil. He must be a very quick judge of the probable home life and habits of new pupils. Their character does not long remain a secret. Masks and veneers slip readily away when in the air. It is this human side which makes civil training so interesting and turns what would otherwise be a drudgery into something akin to membership of the world's greatest library—the infinite variety of men's minds and characters.

I like to believe that the standard of civil flying is steadily improving. If that is so it is because we are getting a better type of instructor.

The quarrelsome, boasting, swaggering, drinking pilot is fast disappearing, if he has not already departed.

Voice Savers

Those who have had to instruct foreign pupils have often used a system of signals, and most instructors find that they can save their voice in this way. Two hands held up with open palms means that the pupil has entire control.

Two clenched hands raised, with index fingers describing little circles means " hold her nose up."

A single hand on edge means straight ahead, and inclined to the right or left means "ease her off" in that direction, while a full turn or use of the control is indicated by the hand held out in the required direction.

It follows, therefore, that when teaching the operative side of landings by means of " normal glide and horizon landings " at 1,500 ft., the instructor holds up both index fingers and moves them from side to side.

Public Safeguards

In spite of all the " red tape " and Government control, flying would be much more dangerous to the general public if it were not for the influence exercised by the schools on their members and by the British Aviation Insurance Co. on the private owners. I would like to suggest that the Air Ministry could be of great assistance to the safety of flying if they entirely revised the issue of licences, which might in future be as follows:—

" A."—Eight hours dual, under licensed instructor, plus three hours solo —for private solo only.

" B."—" A," plus further dual and 50 hours solo for private passenger carrying and also for mail or goods for hire or reward. Flying test as for present " B " at Northolt.

" C."—" B," plus a further 150 hours, plus night flying and practical navigator's exam.—limited commercial.

" D."—A " C," plus a further 500 hours on a variety of types—instructors and unlimited commercial.

At present the Government " A " licence is only a certificate that the holder has done three hours solo in the last 12 months. Some private schools rush their pupils into the air with insufficient experience. But the best clubs, such as the London, at Stag Lane, and the Lancashire, at Woodford, require at least eight hours dual before the pupil is sent solo, and at the London Aeroplane Club we have a local rule which allows no soloist to carry passengers until he has at least 50 hours solo flying and has passed a general flying test similar to that set at Northolt for " B " licence candidates.

During his 50 hours solo flying he is checked over from time to time and allowed to go on carefully graduated cross-country flights alone.

It is a great mistake to allow pupils to hack round an aerodrome doing nothing.

But before they go cross-country the civil pupil should be given (on unsuitable flying days) short personal talks on the four great C.s of cross-country air pilotage—*Compass*, *Clock*, *Chart* and *Common-sense*.

He is shown the triangle of velocities and told that the course always lies between the track and the wind. He may then be taken on a dual cross-country, along a route marked on the map, and asked questions at intervals of a few minutes.

" On what course are we flying now? " (Compass.)
" What is that town on the left? " (Chart.)
" How long since we left ' X '? " (Clock.)
" When do you expect to reach ' Y '? " (Common-sense.)

If he is seen to be chasing the compass he is told to take an outside reference point, such as a cloud or distant hill, and only glance down at his compass from time to time to check the bearing of his aircraft's head. Suddenly the engine stops, it has been cut off by the instructor. The pupil must select his field and reach it by easy curves of constant speed, ending with a flat side-skid. When the visibility is poor and there are no outside reference points it is necessary to provide one inside the aircraft. The most popular method of doing this is by a turn and bank indicator with a separate pitch indicator, thus providing three dimensional references. The fact that it is possible to teach people to fly entirely by this method opens up great possibilities for civil training.

Maintenance Lessons

Those who are going to keep their own aircraft far away from a competent ground engineer should certainly do a course of aircraft maintenance under a practical instructor.

They will learn to check systematically from propeller to tailskid, to clean filters and lubricate controls and chassis.

I strongly emphasise the importance of employing a practical instructor with a good record for maintenance.

Theoretical instruction and an excess of book learning are a weariness of the flesh. I would rather have a pupil who could change a plug in the dark than one who knew 50 facts about the heat treatment or metallurgy of the engines' insides.

Health of Pupils

Flying provides plenty of fresh air, but no exercise. Pupils and instructors tend to become fat and livery.

To counteract this, and to help to create good "hands," my daughter suggests that all flying schools should be provided with ponies. N.F.S. at Hanworth have done this in a small way already. But I submit, however, that to get the full exercise value from horses the pupils should groom as well as ride them.

Part II.

On the Vital Importance of Cost and a Review of Views

The object of civil primary training being to produce the maximum number of safe and sane pilots it follows that they must be produced at the lowest possible cost per head since, as they are themselves paying for their instruction, a high training cost will seriously reduce the number of candidates.

Training costs can be divided among:—

(*a*) Wages of instructors.
(*b*) Rental value of aerodrome and hangarage.
(*c*) Aircraft costs (prime and running).

(*a*) It does not pay to employ a too low priced instructor. If he is incompetent he will produce inferior results and fail to economise aircraft. If he is a good man, but temporarily hard up, he will leave at the first chance of a better job.

But, the very clever and showy pilot is not necessarily the good instructor. Under present conditions of training at Clubs, and allowing for the irregular attendance of civilians, twenty-five complete "A"s per instructor per annum is very good.

There are always a certain number of partly trained pupils who go abroad on business, or terminate their training for reasons of unexpected financial difficulties.

It must be remembered that the instructor's responsibilities increase when the pupil goes solo. In fact they only cease when the pupil leaves the flying school.

Therefore the instructor should be paid either in proportion to the total flying hours of the school or at a fixed wage. He should not be paid for his dual hours as such. Improved organisation and equipment should result in a far greater production of pupils per instructor and increase his wages if possible.

(*b*) Rental of aerodrome and hangarage. From a costing point of view this is a fixed amount per annum whether the land is freehold or leasehold. The rent varies immensely according to locality.

Wonderful aerodromes and hangarage may be had away out in the country, miles and miles from any centre of population.

On such sites "rental per acre per annum" may be low, but as flying hours will be few, "rental per flying hour" may be very high.

On the other hand the huge rentals per acre charged near a big town may, under the energetic management of a competent instructor, work out at a very small charge per flying hour, provided always that the town or district contains a big proportion of potential pupils and that the school is equipped with a sufficient supply of suitable aircraft.

I have not yet suggested a possible method of reducing aerodrome rental charges per flying hour. Some of the American schools have apparently tackled it by planting their aerodromes on cheap ground not too near the cities. Simple dormitory accommodation is provided and pupils attend for standard courses starting at fixed dates. The system should have many advantages in that a set schedule can be prepared, simplifying attendance and discipline.

To produce maximum economy under such a system pupils should make their beds, sweep the dormitories, perform all unskilled and some semi-skilled

hangar and tarmac labour. The only paid staff need be instructor-manager, ground engineer, storekeeper-accountant, and cooks.

Such a school would be divided into red, white and blue watches, so that the equipment and classrooms were in continual use.

That is the only way in which the standing charges can be well distributed.

Even in the London Aeroplane Club we have been running a seven-day week for some time past, with the result that our flying hours have been nearly 600 per machine per annum for the last two years.

(*c*) Aircraft Costs. These can be divided into two parts, the standing charges and the consumable stores.

Standing Charges:—

(1) Interest on capital.
(2) Obsolescence.
(3) Insurance (if at a fixed rate per annum).

From a costing point of view these standing charges are similar to aerodrome rental in that they can be taken as fixed for the year.

Therefore the greater the amount of flying per machine per year the lower will be the standing charge per flying hour.

Consumable Stores are:—

Insurance (if paid by the hour).
Engine overhauls.
Petrol, oil, tyres and tail skid shoes, and the thousand and one maintenance items whose consumption increases in direct proportion to the hours flown.

Type of Aircraft to be Employed

The would-be operator of a civil school run on a scale to satisfy the demand for popular flying is faced with as many conditions for compromise as any engineer.

He must (without subsidy) reduce the costs of training and at the same time increase the comfort and safety. To reduce the standing charge we must have airframes and engines of lower first cost.

(1) I am informed that a large part of the factory cost of aircraft is charges for design to Government standards, control and inspection. (Farnborough, Martlesham and A.I.D.)

The " material-and-labour " cost of the aircraft varies in direct proportion to the weight of the finished aircraft.

The cost of inspection varies in proportion to the number of component parts of which the aircraft is built.

In other words reduce the size and weight of, and number of parts in, an aircraft and you reduce the cost to the operator.

The inspection cost could be still further reduced if a new class of light aircraft were created between the glider and the " power-dive military machine," for whose design and airworthiness not Farnborough but Lloyds would be held responsible.

(2) Aircraft built to satisfy Lloyds would probably carry a low insurance rate.

(3) Strength, simplicity, ease of maintenance, would please both Lloyds and the operator.

(4) Low fuel consumption is much to be desired.

(5) To reduce the accidents from collision on the ground and in the air a forward and sideways view as good as the F.E.2 b, or a modern glider, is absolutely essential.

The present tractors are terribly blind and unless we revert to the " pusher-view " a big increase of flying will result in more collisions. A decrease in the collision risk should result in a decreased insurance rate.

(6) For the instructors and pupils the following points are important:—
Freedom from vices, sudden stalls, hunting on elevators or tendency of machine to take charge.
Freedom from oil throwing, fumes in the cockpit or draughts down the occupants' necks.
Freedom from propeller swinging.

Instructional machines should be designed to be reasonably flyable without springs on elevator or rudder, particularly rudder.

Besides the virtues demanded above the operator will expect to find a really comfortable position for pilots of all heights, widths, ages and sexes, and easy communication between instructor and pupil.

Colossal climb, top speed or diving power or ability to fly inverted will not be expected or required of the future civil training aircraft. The small proportion of pilots who wish to learn and perfect themselves in advanced aerobatics or train as mail pilots will attend one of the semi-military schools, and will wear parachutes.

I have tried to indicate a method by which the prime and running aircraft costs may be reduced in the near future, but that alone will not suffice to reduce civil training to the point where the general public can afford to be trained.

To be really popular, training costs must come down from about £45 (unsubsidised) to £10 per head. As far as possible office and other workers must be prepared in the dark winter evenings.

We can bring to our aid help from a variety of outside sources:—

(i) The use of the feet to create and correct yawing movement can be taught in lighted drill halls or flood-lit school yards by mounting pupils on small petrol engine trolleys, hand throttle controlled and steered with a rudder bar or pedals.

Obsolete airframes can be mounted free to swivel on posts in exposed and windy situations in which young pupils may amuse themselves moving the controls and trying to steer compass courses, as done by Squadron-Leader England at Lee-on-Solent.

(ii) Air Service Training at Hamble have a device in their classroom which resembles internally the hooded cockpit of an instrument-flying instructional aircraft. There is no reason why this should not be used to familiarise a pupil with stick and rudder movements.

I have made the experiment at the London Aeroplane Club of taking a member of the ground staff who had received no flying training and placing him in the hooded cockpit of the blind flying machine. His reactions in the air were better than the average pilot trained by normal methods. This is possibly because he had no preconceived ideas of flying the machine from the sensations of his deep muscle. I believe the Air Force have carried the idea further. Perhaps there is someone here who can give me further news on the subject.

(iii) The third aid from outside should come from the Gliding Clubs. The London Gliding Club, at Dunstable, in particular have displayed an originality and resourceful invention which make the conventional school or club look like a canal boat beside a sailing dinghy.

They have brought communal co-operation to a fine art, built a village of huts and hangars and devised an effective means of hauling gliders to the hill-top, all at a very small cost.

From a flying training point of view they are interesting in that they start their pupils on what are virtually long landings by pulling them over the surface of the flat ground on a half-stretched elastic.

This method might be interpolated between the A.S.T. instrument device and dual on the low-powered aircraft.

They have also a wide variety of types. I do not know if this is as valuable to glider training as it is to power training, but 20 hours solo on eight different types of power machines are worth 50 hours on one type.

Unfortunately, a variety of types and engines does not help to keep down costs.

Co-operative or Group Flying

Such a school as I have visualised would be of no use for those in regular employment. But for such people the last two years have seen the beginnings of a new type flying club.

The examples which occur to the mind are the Household Brigade and the 'Bus Drivers' Clubs.

In both cases a weekly or annual amount per head is levied on all members of the particular profession or occupation. I believe I am correct in stating that all officers of the Household Brigade pay 10s. per annum, and those who happen to be stationed near Heston obtain flying at very low rates. Similarly, all the members of the London General Omnibus Company's Sports Club pay 6d. per week and those near Broxbourne fly for a nominal charge per hour.

This type of group club should become very popular.

We need not only cheaper aircraft but a better forward view.

Where hostility to the single engine pusher exists to-day in the present generation of pilots, the attitude of mind is not the result of sane reasoning but has been sucked in with their bottle-milk at second and third hand from the descendants of Gosport. It is one of the more evil relics of the Smith-Barry revolution.

Pilots who have never seen a pusher except in a photograph, inform one solemnly that at the slightest hint of engine trouble the propeller bursting into a thousand pieces cuts the outriggers, and the crankshaft comes through one's back. Why not use a modern forged-one-piece metal propeller and why have outriggers?

If I may be personal for a moment I should like to mention that my first forced landing took place after about two hours dual and 20 minutes solo. The aircraft was a Maurice Farman Longhorn. The landing was made on an earth dyke wall across a ditch. The propeller and the tail-booms were broken. The engine did not hit me in the back.

The machine was flying again in a few weeks.

Later, on another occasion at Vert Galand in the winter of 1916-17 I saw an F.E.2b, make such a tail high landing that it practically flew into the frozen ground. The undercarriage was wiped off, the propeller and tail-booms broken; the nacelle skated along the ground on its forepart; the engine, a 160 Beardmore, weighing over half a ton, did not push the crew in the back and they stepped out completely unscratched.

Remembering that false landings from engine failure are to-day the exception rather than the rule, pilots should free their minds of bias and ask themselves this question :—

"Is it better to have 100 per cent. speed, 100 per cent. climb and full aerobatic performance and suddenly leave this world by hitting a factory chimney or a flagpole?"

"Or is it better to have 95 per cent. speed and climb and limited aerobatics and always to be able to see where you are going on the ground and in the air, have freedom from oil splashes, exhaust fumes and icy eddies of the slip-stream and go on flying until you are too old to leave the fireside?"

The other party who are accused of resisting the return to the pusher appear to be the senior design and works management staffs of the factories.

After all they have become experts in their own lines, the design and production of fighters, flying boats or whatnots and one cannot expect them to change at their time of life.

Therefore the popular light aeroplane for cheap civil training will probably come from a firm yet unborn whose staff will be picked and trained for the new work.

The requirements outlined above seem to indicate a pusher of small horsepower and light loading quite unlike the machines which have served us so well for the last six years.

It is quite possible that in order to keep down the frontal area, concentrate the weights, and simplify the communications and the dual mechanism, the designer will have to mount the instructor close behind and astride the pupil-pilot's seat, as was the custom on the Longhorn and Shorthorn Farmans.

An alternative is side-by-side as done by the Wright Brothers.

For better civil primary training we require :—

More sanity from our constructors.
More sanitation on our aerodromes.
More equity in our regulations.
More equitation in our spare time.
More levity in our lectures.
More levitation by our legislators.

I wish to acknowledge assistance from Mrs. Cockburn-Lange for the photograph of head-on collision of two tractors (taken by her late husband); Mr. S. O. Bradshaw for preparing cartoons and black and white sketches; and to the following for slides :—London Gliding Club, Air Service Training, Westlands, R.Ae.S. from their collection.

Discussion

Group Captain J. M. Baldwin : It seemed to be assumed that military flying schools had everything they wanted, and that money was no object. That, however, was not the case; it was just as difficult for them to get what they wanted, and they were as careful as were the civil schools with regard to breakages.

Some people might still think that there was a great difference between the requirements of military and civil instruction. He maintained, however, that there was not; a system might be adapted to the particular requirements of civil and military aviation, but fundamentally it was the same system.

Commenting upon the author's reference to the fact that much mud had been slung at pre-Gosport instructors, he said that he had learned to fly by pre-Gosport methods of instruction from the people concerned, and in his experience they had not deserved the criticism directed to them. Those who had taught his generation of pilots had developed a system of their own, handicapped only by the entire absence of modern conveniences of inter-communication and dual control, and he would be the last to disparage their efforts.

He agreed that the civil schools had borne the brunt of the training work at the beginning, and that the early pilots were all trained at civil schools. Methods of instruction in later years had become really excellent. The military and the civil methods were in line, and he emphasised the importance of maintaining close contact between the civil and military schools. If war were to break out again, the military authorities would expect to find fully qualified instructors from the civil schools for military training.

It was necessary to exercise some caution in regard to the adoption of a system of signalling to pupils with a view to saving the instructor's voice. He hoped that the majority of instructors would rather endeavour to improve and strengthen their voices than to invent signs, because in his experience the calm, steady voice of the instructor had a much more beneficial effect than any signs could have upon a pupil who was just on the border line of panic, having just missed a tree-top, over-shot a landing, or just entered a cloud.

With regard to the " A " licence system, he suggested that pilots should not be able to re-qualify merely by putting in three hours' flying per year, and

that it would be better if pilots were compelled to do a certain period of flying per quarter. During the months of May, June and July he had visited the majority of the popular civil aerodromes, and had met certain brother pilots who had solemnly told him that they had only another 50 minutes' flying to do in order to complete their three hours, and that they proposed to do the 50 minutes that week so that they need not appear again until the following June. He considered that a man who stood down for eleven months of the year and then put in three hours flying in order to re-qualify for his " A " licence was a danger.

Finally, Group Captain Baldwin expressed complete agreement with the author that instructors should emphasise to their pupils the necessity of keeping really fit. If one were a little off colour, and had to face a bad patch of cross-country flying, one's reaction was nothing like so quick as when in perfect health.

Flight Lieut. JENKINS: Discussing the use of separate controls, he said that experience of teaching instrument flying had proved that a great deal of benefit could be derived from teaching the *ab initio* pupil, in the elementary stages, to use the controls individually. He rather disagreed, however, with the author's view that it was difficult to master the rudder control with the feet. The stick was a good deal more difficult in so far as it was used for two purposes, *i.e.*, movements in the rolling plane and in the looping plane, and when co-ordination was attempted, that was where the real difficulty arose. He doubted whether very much could be done with any sort of mechanical contrivance on the ground during the really elementary training of the *ab initio* pilot. The apparatus illustrated by the author of the paper was used at the A.S.T. essentially for teaching the elementary side of instrument flying, and was not used at all in connection with the training of *ab initio* pilots. It had been tried in *ab initio* training, but its use for that purpose had been discontinued. It could be used with advantage, however, for the development of mental agility—co-ordination between the brain and the eye. A good deal of benefit would be derived from half-an-hour of physical jerks each morning, for, after all, it would be agreed that the man who was physically fit would fly solo earlier than the man who was not physically fit. He agreed with Group Captain Baldwin's views concerning the danger of using signs in order to save the instructors' voices.

As to the type of aircraft to be used for training purposes, it would probably be a most interesting experiment to revert to the pusher. It was easier to fly a pusher than a tractor, and the pusher could be landed more easily, particularly by reason of the excellent forward view from the pilot's seat. Ease of handling was also due to some extent, he believed, to the comfort of the pusher, by reason of the absence of the slipstream, and so on.

Commenting on the author's statement, anent design characteristics, that " instructional machines should be designed to be reasonably flyable without springs on elevator or rudder, particularly rudder," Flight Lieut. Jenkins expressed the opinion that it was far more desirable to have a spring on the rudder than on the elevator, because, after all, the rudder was a negative control, whereas the elevator was a positive control, and the " feel " of the rudder was comparatively unimportant, whereas the " feel " of the elevators was of great importance, particularly when landing.

The author's remarks concerning the forward view from the present type of tractor aircraft were justified, but to a certain extent the difficulty had been overcome by the inverted in-line engine, and if the machine had adjustable seats also we were getting nearer to what was wanted. Side-by-side seating should be discouraged, because unquestionably there was very bad visibility on the side not occupied by the pilot.

Flight Lieut. W. E. P. JOHNSON (A.F.C., A.F.R.Ae.S.): Referring to the question of change types, he said it was stated in the paper that 20 hours on eight types was better than 50 hours on one type. He would go further than that, however, and would say that five hours of intelligent solo flying by an

inexperienced pupil on five types was worth 50 hours solo on one type. In any case, he agreed with the author, in principle, as to the value of change types, and he suggested that the ideal training aircraft included means for varying considerably its own characteristics. He had had a little experience of teaching on a Fairey III.F (dual), and had found that any reasonably intelligent pupil could get better instruction and amusement out of one hour of flying in that machine than from ten hours in some types, as, for instance, the D.H.9.A., because the Fairey had certain variables, not unconnected with wing flaps, and things of that sort, so that one could vary the gliding angle, the effect of controls, and so on. These advantages were all combined in one aeroplane, without involving very great additional expense. He pointed to the instructional benefits of air brakes, by which a gliding angle might be varied. Even the mere act of changing sides in a side-by-side aircraft had, for a keen pupil, a zest and stimulation which was found to be useful. Perhaps that did not last long, but the pupil had to look in a different place, owing to the bad forward view landing, the throttle was on a different side, and the principle had points worthy of development. Therefore, he would like to see training machines with side-by-side seating. There were important advantages other than those he had mentioned, if they were applied intelligently.

There were great advantages in using wheel brakes. They expedited instruction; one could get a machine round more quickly, and could effect more landings in a given instruction period. Their natural adjunct was the tail wheel; it enhanced the advantages of the wheel brakes and improved the durability of the aircraft.

Therefore, he commended " variability " and completeness of equipment in training aircraft as the most important desiderata, so that pupils could take advantage of modern developments.

With regard to the technique of instruction, it was refreshing to hear an instructor, who presumably earned his living by instruction, giving an idea of his methods. It was a good thing that instructional methods should be ventilated in places where people thought about these things, and Major Travers was both bold and wise in disclosing his ideas of system and method. Major Travers had touched on basic principles when he had referred to " operative and optical " methods. It might be encouraging to mention that Dr. McCurdy, the eminent psychologist, of Cambridge, had made very favourable comments on that sort of instruction, viz., where one definitely considered difficulties that the pupil would be up against and how to meet those difficulties one by one, and finally combined them in one thing, such as, for example, a landing. The difficulties of landing might be divided, roughly, into the difficulties of optical judgment and manipulative skill. It was his experience that if one dealt with optical judgment first, and manipulative skill second, one could teach landing in half an hour, with a reasonable aircraft, instead of the usual two or two and a half hours, and so reduce the possibility of collisions, and so on.

He was against orthodoxy in instruction, but it could not be denied that certain fundamentals should be observed if the public were to be taught safely and economically. Major Travers and himself shared the view that the fundamentals of flying instruction were capable of standardisation and formulation, and it appealed to him rather strongly that those responsible for licensing instructors would do well to make use of such standards as were deemed to be essential standards as criteria in judging whether a man should or should not be an instructor.

Dealing with the question in the paper as to whether there had been any *ab initio* training by instrument, he believed that in Denmark two pupils were instrument-trained under a hood and had competed with two other pupils trained by other methods. All four pupils were carefully chosen, tests having been applied to prove that they were all of " average " intelligence. The results had

indicated that instrument training was possible, but there was no evidence that it had specific advantages.

The paper by Major Travers contained a text: " We need, not only cheaper aircraft but a better forward view." Flight Lieutenant Johnson submitted, however, that with a better metaphorical " forward view " they could secure cheaper aircraft. The obstacle to this view at the moment, it seemed, could be expressed by the code word " FAIL'D," which word was formed by the initial letters of " Farnborough," " A.I.D.," " Inspection," " Legislation " and " Departmentalism." He had a great respect for each of the integers, but the sum undeniably constituted the chief obstacle to progress in civil aviation. If they could omit this code word from the aeronautical vocabulary, they would get a better " forward view " and cheaper aircraft.

Finally, he pleaded for business control in civil aviation. To this end, he would like to see it develop under the interested eyes of those whose livelihood was at stake—just as shipping had developed—rather than under the rather chilling gaze of pensionable officials.

Captain the Right Hon. F. E. Guest: The subject seemed to represent the foundation of civil flying, and he submitted that it was a pity to try to condense a subject so wide into the compass of a paper. The sub-headings indicated that there was enough material for at least four lectures. Aspects of the subject which were deserving of closer attention than the meeting had been able to give them were, for instance, systems of instruction and the type of aircraft to be employed; and other matters of vital importance to the private owner were costs, maintenance, etc. The Society had started, by this paper, a hare which ought not to be allowed to stop running for some time, and as the result of two or three debates on various aspects of the problem such as he had indicated, valuable information would be spread around. He was amazed at the skill with which the author had covered so much ground, though perhaps in that way he had avoided being pressed too hard on any particular point. He suggested that a committee might be formed to arrange a series of lectures on various aspects of the problem, and he promised that he personally would attend these lectures.

Major Mealing (Air Ministry): He was not sure whether it was safe for him to speak, after having heard what some people thought of the Air Ministry. Major Travers had referred to red tape and had pleaded for more equity in the regulations; and then he had made suggestions for tightening up the regulations. One did not know what the result of that would be. It would probably be said that the iniquitous Air Ministry was tightening its grip on civil aviation.

Discussing the section of the paper dealing with public safeguards, where licences were divided into four classes, he said that the classification was a matter of opinion, so far as the technical requirements were concerned, but it must be pointed out that the terms of licensing were always subject to international requirements, a fact which had not been mentioned in the paper. There was not much point in having very stiff licensing regulations in this country if it were possible for anyone to come over here from another country and become a danger, because that country had less stringent requirements. Whatever was done in tightening up the requirements—and he agreed that they should be tightened up—one must remember the international aspect.

Major Mealing was glad to hear Flight Lieut. Johnson support the side-by-side seating in training machines, because many arguments were put forward on that subject, not so much from the point of view of actual training, but from the point of view of the psychological effect upon the pupil. It had been said that pupils rather " got the wind up " when the instructor was too near them, but he would like to hear the opinion of Major Travers on that matter.

Commenting upon references which had been made to the danger of entering some civil aerodromes, Major Mealing said he could only ask if civil pilots had ever tried to get into some of the R.A.F. aerodromes.

Mr. Lowe-Wylde: The air had to be regarded to-day as a new medium of travel for everybody. Their motoring schools had never set out merely to provide people as chauffeurs, motor coach drivers or lorry drivers. They must try to visualise the day when everybody would fly as easily and as commonly as people drove motor cars to-day. At the present time flying was difficult; it was going through a stage similar to that which was experienced in the motor car world a few years ago, when it was considered ridiculous for anyone to set out in a motor car for a journey of any distance unless he possessed mechanical skill. In his opinion one could only learn to fly by flying solo, so that the correct thing to do was to train a man to be able to fly solo as quickly as was safely possible. Another point was that the civilian pilot did not necessarily want a high performance, and if the effort to obtain high performance were cut out, they would get machines very much safer than those of to-day. With regard to training on a multiplicity of types, if a man, however taught, had really a developed air sense, he could fly and land most machines without risk of breaking them. He urged that they should get as many people as possible into the air on a low-power elementary type of machine—so that flying would be within reach of a greater number of pockets—and let them acquire air sense. From them they could find those who would make good material for military and commercial pilots.

Mr. W. O. Manning (Member of Council): As to the types of machines for training, there was no reason why a pusher should not be built if people desired it, and he urged that the question as to whether a pusher or tractor should be used was one for the user rather than the designer. A pusher certainly had the advantage that it gave a good forward view, but there were difficulties in other directions. It was doubtful, to say the least, whether any of the existing engines would be at all suitable for use in a pusher, so that some special types of engine would have to be designed. The exhaust valve was placed forward in the tractor engine in order to get the best advantage from the cooling air. In the pusher the engine would be turned round, and it might be expected that the exhaust valve, and the region around it, would be over-heated. That criticism would not apply, of course, to the ordinary four-cylinder vertical engine. On the other hand, the present engines were bigger than would be necessary if the author's design were adopted.

From other points of view there was not much between the two types of machine. If one wanted the best possible performance out of any machine, there was no question that it could be obtained much better with a tractor than with any other type. He believed our engine designers had not gone quite so far as those in America in suppressing oil throwing. He had seen Colonel Lindbergh's machine after it had flown the Atlantic and there was not a spot of oil on it anywhere.

He did not think that the risk of a propeller bursting and doing damage to a machine need be regarded seriously to-day, but with a pusher machine the various appendages of pilot and passengers would have to be attached to their persons more securely than they are attached to-day. For example, if a cap were blown through the propeller it might have serious consequences.

It would be well to pay a little more attention to various matters of detail. For example, the method of attaching the ailerons by means of two or three screw eyes, and pushing a rod through, belonged to the very early days of aviation, but it was still in use on many machines. It should be possible to use a bearing, with a provision for lubrication. He believed that when the special training machine came to be developed, with attention to detail, the cost of maintenance would be reduced.

Mr. Gordon England (Member of Council): He regarded the paper as epoch-making, and emphasised the fact that it was concerned with "civil" primary training. He expressed the view that most of the speakers other than

Captain Guest—who was the only speaker who had indicated that he had grasped the real significance of the paper—had confined themselves to expressions of opinion which were far more suitable to a consideration of instruction for military aviation.

In his view, the curse of civil aviation was that designers of aircraft, test pilots, and instructors were all military minded, and this military mind, so far, was the theme of most of the discussion that had taken place, and he submitted that a subsequent examination of their remarks when committed to cold type would show conclusively that they possessed military minds.

What was needed was an appreciation that the civilian who desired to fly had no such mind, and until the manufacturer, designer, test pilot and instructors were able to assimilate the civilian mind, progress would be deplorably slow.

Even Major Travers, who had shown such commendable spirit in being able to break away from the military mind, still showed definite traces that he had not entirely cleaned the mental stables. This was emphasised by his reference to physical fitness. It was absurd to expect a high standard of physical fitness in the ordinary civilian. He would never take up flying if it involved getting himself into a condition of athletic training.

It was a condemnation upon aircraft and aircraft design that such unreasonable demands should be made, and those who were hoping to win his favour by teaching him to fly and then selling him aircraft must recognise that fundamental fact, and the authorities also must appreciate it.

The suggestion that high speed was essential to the majority of types of civilian aircraft was another of the will-o'-the-wisps that manufacturers and designers were chasing in connection with civil aviation, that is, if one regarded civil aviation as being conducted by the "man in the street." An examination of the flying done by those indulging in civil aviation would clearly show that over 75 per cent. of the hours flown were above or around aerodromes. This was largely because the aircraft at present in use were quite unsatisfactory for use across country in the hands of the average man.

If one was to select, say, 24 places about the country and an aircraft which had the capacity to land in a normal field when flown in a normal way, but having only a top speed of probably 60 miles per hour, and matched this against the modern so-called light aeroplane, the average time taken to reach the ultimate destinations would be heavily in favour of the slower machine.

Aircraft had not progressed in ease of handling since the war. As an illustration of the retrograde progress he recalled that, as far back as 1911, he and the late Mr. Pizey had conducted an aviation meeting for a week from a small field half-way down the cliff at Ventnor, Isle of Wight. They had carried nearly 80 passengers from that field on the two Bristol box kites used for this purpose, and no damage was done to either machine until the final flight when Mr. Pizey had a bad landing.

Many of his friends had been incredulous that such a thing could be done, and told him point blank that there was no field in Ventnor itself where a light aeroplane could even land—let alone conduct flying meetings in company with a second machine—and yet, until quite recently, that field was still there and unspoiled.

They had got to get back to that type of aircraft; an aircraft that the average man could use anywhere at any time in the country without having to satisfy himself that there were aerodromes available. Any large field should be a good enough aerodrome for a truly civilian machine.

It was a dismal thing to contemplate that after all these years all that had happened was that aviation got more difficult for the "man in the street."

Reference had been made by Group Captain Baldwin to the danger involved when a man obtains a civil licence and flies for only three hours in the year, in order to requality. Why should a man do that? A little examination of that

problem would show the fundamental weakness of the present development of civil aviation.

He pleaded for a simplification of flying within the confines of Great Britain. It should not be necessary to have a licence which met with international acceptance in order to get people to fly in Great Britain. A great volume of flying could be, and would be done here, and a real development would result, if the authorities would co-operate in encouraging flying in this way.

Pilots who were encouraged to fly with limited national licences would very soon develop sufficiently to reach the standard required for an international licence; meanwhile, useful flying would be done and a vast industry built up of an international character, but before all this could be done it was obvious that suitable machines had to be available, and an entirely new type of aircraft free from the military mind was a necessity.

Finally, Mr. Gordon England suggested that the author of the paper had in no way overdrawn or exaggerated the situation. Supposing the paper had been read to an audience of the " men in the street " instead of to those keenly interested in aviation? That audience would have been bound to come to the conclusion that they would never engage in civil aviation. It was far too difficult, dangerous and costly, and apparently had no utilitarian possibilities.

The paper, regarded from that angle, was indeed most damning evidence of the present futility of civil aviation. The author, as a propagandist to the ordinary civil population, would be a deplorable failure if he used his present paper as a basis for making an appeal to them to engage in aviation; but, regarded as a contribution to an intelligent and informed audience, it was a great tonic and bound to leave a very deep mark in the minds of all thoughtful people who wished well of civil aviation.

Mr. M. L. Bramson: He suggested that if Mr. Gordon England had had the experience—and surely he must have had it—of sitting in a machine cruising at 80 m.p.h. against a 35 m.p.h. wind, his conclusion as to how the cruising speed of aircraft affected the practicability of civil aviation might change. If one wanted to make practical use of flying, and to travel from one point to another, one must be able to deal with the not infrequent contingency of a strong unfavourable wind—without getting too desperately bored in the process.

With regard to the spring loading of the joystick, it seemed that one's first reaction to that was that it was appalling that the fore and aft " feel " of the joystick could never be relied upon to give any indication as to the state of flight. One used to be told that one should " feel " an aeroplane; but a spring-loaded stick, where the spring loading was variable at will and by anybody, and where effort of memory and sight was required to find out what was the state of the spring loading at any time, was an appalling contrivance with which to teach people to get the " feel " of a machine. On the other hand, there was the converse point of view. Perhaps the fact that the " feel " of the joystick was so completely unreliable as a guide to the state of flight had prevented accidents, because it had taught people to ignore the " feel " of the stick and to fly by horizon and air-speed indicator.

Mr. Bramson urged that inertia effects should be considered in flight training, for he had come to the conclusion—after about 13 years of flying—that far too little emphasis was laid on the acceleration and inertia effects on the aircraft. One was taught to deal with the state of the aircraft when the state did not really matter, because the fact that it was flying showed that the state of flight was safe. When a man was being taught to find out, say, from the air-speed indicator what the machine was doing, he should be taught, not so much to consider what the reading was, but whether it was increasing or decreasing; that was the point that really mattered. Similarly, he had never found, either in books of instruction or in his contact with flying schools, that sufficient explanation was given of wind velocity gradient. Everybody who had flown on a windy day had

experienced a sudden drop when coming in to land. If one happened to come into an aerodrome over a hedge one attributed the drop to turbulence caused by the hedge; but the same thing occurred when one was in the centre of a vast field. The effect of the inertia of the machine in those circumstances was important, and should be understood. Some people pulled back the stick, so as not to hit the ground; they should do the opposite, *i.e.*, push the stick forward, so as to allow the machine to accelerate and thus compensate for the loss of relative speed.

Finally, Mr. Bramson protested against the commonly advanced and popularly adopted motor car analogy, and emphasised that aeroplanes were not analogous to motor cars. Aeroplanes would never become door-to-door vehicles, as motor cars were, and we were merely fostering a fallacy by pretending that they would. The proper analogy to an aeroplane was that of the yacht. An aeroplane, like a yacht, required a port of some kind, even if it were only a small field; it had the advantage over the yacht, however, that its ports were not confined to coast lines.

Lieut. R. L. PRESTON: He considered the author's suggestion that a pilot should do eight hours dual, plus three hours solo before obtaining an "A" licence was wrong, because that requirement would dissuade the "man in the street" from learning to fly, on the ground of cost. At some schools, at £4 an hour, £32 would have to be paid before going solo. It was assisting subsidised clubs. The number of people who learned to fly and then gave it up because they could not afford to go further was tremendous; he believed the percentage was over 50, and it was by the use of aeroplanes such as the power glider that the cost difficulty might be overcome. Commenting upon Group Captain Baldwin's criticism of the system by which a pilot had to fly for three hours per year in order to renew his "A" licence, Mr. Preston suggested that three hours was satisfactory. If the period were extended, a large number of people would not trouble to renew their licences. Many people had asked him how much flying had to be done in order to renew their licences, and they had said that they could just afford to pay for three hours solo per year. The subject of cost was most important in private aviation to-day.

Finally, he expressed agreement with Mr. Gordon England's remarks concerning the military and the official mind; it was extremely damning to civil aviation at the present moment and contributed to making private flying expensive on the excuse of protecting the public, but are there any known cases where injury by aircraft has been done to the general public in England? Compulsory third party insurance would protect any public claims.

Mr. MURRAY: If the Air Ministry continued to superimpose further regulations on those existing, the industry would rise up in arms. He suggested that the Air Ministry should really make sure that those who were responsible in the industry were competent to carry on their job, and then should leave them alone to get on with it.

Air Commodore J. A. CHAMIER: He would like to ask whether Mr. Travers is inclined to believe that pupils could be taught to fly by instruments rather than by the senses, provided that a cheap and light single instrument can be found of which the interpretation is simple, direct and easy, and which is placed in the normal sight line of the pupil rather than low on an instrument board. The remarks he made about an *ab initio* pupil and blind flying makes one think that he had some such idea in his mind. He attached the highest importance to this point.

If they could get some "mechanisation" into training and subsequent flying, and depend less on these easily deceived senses they would expedite training, reduce its cost, and save lives.

The Hon. Lady BAILEY, D.B.E. (*communicated*): Through his interesting lecture, under the heading of "Civil Primary Training," Major Travers raised

many questions, which in the discussion following were debated from what appeared to be varying points of view. But these it appeared really all applied to one and the same thing, namely, the reasons for the existence of the flying clubs with their instruction to members. She supposed that one may presume these reasons to be, in the one part, the motive to create a reserve of persons with some knowledge of aviation for drawing on in the event of war; in another, the motive to educate public opinion to the necessity to develop aviation in this country for the advancement of design and the aircraft industry of this country.

Another reason, that there are a great many enthusiasts who are members of the flying clubs—those who wish to buy an aeroplane for their own use; those who wish to take up aviation in some branch as a career; and those who wish to fly the club machines in their spare time. For the flying clubs to continue the " primary teaching " they must have a continual influx of new members. If there is to be no further practical objective to this instruction, the numbers of new members to the flying clubs must some day fall off.

It would be to the benefit of the members of the flying clubs if those of them who wished to get further knowledge and experience had greater chances of getting jobs in aviation. As there is only a portion of one regular commercial air service—that from Croydon to Lympne—in this country it would appear that there is no scope in this direction at all. The flying clubs and flying schools and many persons have all worked to create in the individual an interest in aviation, and to create in the towns an interest in establishing aerodromes and airports, and are now endeavouring to keep alive this interest. She thought this " keeping interest alive " part is what is going to fail if there is not some further purpose to the initiative already given.

The individual needs the chance of a job, or at any rate to see more practical use made of aviation, once he has learnt what its potentialities are and can imagine even a short way along the lines of what these may become with the continual improvements of aircraft and aircraft instruments; and the towns will want to notice the start of some practical progress and benefit in air travel that they can use and see used in regular air services to and from the aerodromes which they have established.

If she might be allowed to say so, she had long thought that for these and many other reasons there is great need for the establishment of regular internal air services locally in England.

The flying clubs in England really have done valuable work up to the present, and it were a pity to allow them and their organisation in landing grounds to drop out, either individually or as a whole. If this were to happen, the facilities for private flying, air taxi work and any proposed air services would revert to the aerodromes Croydon and Lympne, the Royal Air Force aerodromes (where commercial air services might not be permitted to operate), and privately owned aerodromes.

Is it not time to provide an objective, and that the main theme were the running of local regular air services between the industrial centres of England, Scotland, Ireland and Wales, linking up those centres directly by air transport with the great quantity of air services that ply daily between the various industrial centres of Europe and the air routes to Africa, India, Australia, and through Russia, and so forth? With the prospect of these routes there would be more development in advanced types of passenger-carrying British machines, as at the present time the only market for these appears to be a limited one in the Colonies. There would be a chance for members of flying clubs who could pass a certain standard of efficiency to get jobs in some branch of aviation.

And it could not be argued that by gaining experience the members of the public taught at the flying clubs would become less efficient. If there was need to draw on reserves for military flying at any time, a large commercial aviation transport with its organisation, routes, personnel and equipment would produce

more in experience to draw from than two score flying clubs. This is just what most of the European countries possess and what this country at present does not. The air transport services could then draw from the flying clubs and schools and other training centres.

Further, once given a purpose, such of the industrial towns as could afford it would soon be *demanding* an aerodrome so as to be " on the map " as regards air transport facilities and communications. Would there be any reason—if regular air services were established in England—to prevent the " dole " in the various districts being paid to the unemployed as wages for work in clearing an aerodrome and building a hangar? If foreign investment by wealthy Britishers and others resident in England could be curtailed, and investment in the development of British and Empire concerns induced, there would be no question as to the possibility of getting support to get these necessary transport developments established. If a tax could be raised on foreign investment it would turn at any rate a portion of it to home and Empire development, which from all quarters so affected must bring relief, be a stronger bond of Empire, and help our own trade to absorb unemployment. In her humble opinion it is not a question of these air services at once paying a profit, it is the necessity to have them, and they are not yet in existence; they will be a novelty when they start and it will not be everyone that will realise their full benefit when they first start. These objections which are always raised are only part of the process of the establishment of any new project.

But it is the question of lay-out and planning and of trying out the most efficient and economical mode of operating these services to meet the requirements of as many districts as possible. Once the potentialities of air transport are brought home to the realising of the business and trade heads throughout the country by transporting them comfortably by air, then the way is cleared to get support for the development of the longer air routes and for the inter-colonial and local colonial air services and traffic. She was sure that it is in the being able personally to see, to hear of and to experience the local commercial air transportation in England, that is going to start the ball rolling. Like most other concerns the initial stages have to be planned and passed through, whether these are inaugurated now or later on. In comparison with many European countries they were much belated, and there is a good deal of ground to be made up. So soon as stunt flights and their vivid word picture descriptions can be toned down, or so soon as the general population get a chance to travel by air and realise the real stage that air transport has reached, perhaps there will be more chance to get the ear and confident support necessary to inaugurate these services.

Since the start of the air service to South Africa she had heard repeated expressions of wonderment and admiration of the facilities now afforded to people who have flown to mining districts in far apart scattered places, in so short a time and with ease. These experiences of air travel have been in the course of work and inspection and so forth, and when it is a friend who has ventured and accomplished in a short space what otherwise took so long, the account sinks in and will do more to generalise flying than all the tales of sharks and crocodiles and elephants and sunstrokes, interesting and amusing as any of the real ones of these may be. As the Royal Aeronautical Society, through Major Travers, has brought this matter forward, would it be possible to follow it up? May she put forward the suggestion that the interest in flying has been aroused, but that to keep this alive there must be an objective, and that from a small beginning in the way of local commercial air services in England she thought this would become assured?

The CHAIRMAN: The question of the qualifications of holders of the " A " licence was under review. That review was being undertaken not only by those about whom so many speakers had made unpleasant remarks; they were calling

into consultation the Instructors' Panel of the Guild of Air Pilots and the representatives of schools and clubs, and he hoped that as the result of the discussions some very marked improvement would be effected.

Reply to Discussion

Reading through the paper and criticisms at leisure I am struck by the friendly nature of the discussion which followed and the tolerance shown by the speakers.

Group Captain Baldwin naturally regards all civilians as potential emergency reserves for the fighting services and would like to see them as well trained as possible, but we agree that a healthy population is to be preferred to an unfit one in any case. I would prefer his method of keeping fit by horse exercise to Flight Lieut. Jenkins' suggestion of physical jerks. Horses appear to give people a sympathy and understanding and develop the rider's intelligence in a way which is completely absent from physical jerks.

Flight Lieut. Jenkins agrees that the Air Service training instrument flying apparatus could be used with advantage to teach co-ordination between hand and foot and eye, and it was for that purpose that I proposed to use it on days or nights when civilians could not get into the air.

This remark will also serve to answer the communicated letter from Air Commodore Chamier, to whom I would say, that so long as we have to rely on visual aid for landing an aircraft, it will be necessary to give visual training. Apart from training for flying near the ground and landing, some such device as Air Commodore Chamier suggests might be useful.

The speeches of Flight Lieut. Johnson and Captain the Hon. F. E. Guest are mainly constructive in that they plead for an open mind, adaptability and progress in the art of instruction.

Major Mealing very skilfully puts his finger on the weak point of the paper, which is that I did not draw a sufficient distinction between the two parts (*a*) dealing with the situation as it is and (*b*) forecasting what we should like to see in the future. (*a*) The suggestion that all pupils should receive eight hours' dual, referred to the type of aircraft at present in use and was an attempt to bring less carefully run schools up to the standard of the London Aeroplane Club; while my suggestion of four separate licences was an attempt to raise comment on the futility of the present "A" licence.

In neither case was I entirely successful, and (*b*) sheltering myself behind the opening paragraph of the paper, I would say that all that should be necessary for domestic aviation (pilot flying solo in England) should be third party insurance.

While fully appreciative of all that Mr. Lowe-Wylde has done to make practical the featherweight aircraft, I do not agree that one can only learn by flying solo. Solo flying should be alternated with dual to prevent the crystallisation of bad habits. But the more suitable the aircraft are for civil primary flying the less time will be wasted teaching pupils to avoid bad handling of controls, and even with the most perfect aircraft some people will try to be foolish. Good instructors are an asset to the industry, because they will set a sane standard which pupils will imitate.

While agreeing with Mr. Gordon England's remarks about slow machines for learning, I do not believe that the touring machine should be slow; rather it should have a remarkable speed range so as to get in and out of the small fields and yet cruise against a head wind without undue loss of time. But that is getting outside the scope of the paper.

I would suggest to Mr. Bramson that flying is a co-ordination between hand, foot and eye, whether the eye is watching the horizon or an instrument.

Inertia is mainly experienced when dealing with sudden local variations of wind speed and matters little when not very near the ground. Regarding the wind velocity gradient near the ground, it has been my custom to point this out to pupils for many years past, though not using this name for it. I emphasise the reduced speed of the wind near the ground due to ground friction.

I most strongly disagree with his suggestion that the stick should be pushed forward when within a few feet of the ground. If he tries to do so he will drop the machine heavily on its wheels. The proper method is to continue the normal glide until closer to the ground than usual and ease the stick back quicker than usual, when a perfect three-pointer will result.

The 557th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

First Meeting, Second Half, 68th Session

The First Meeting of the Second Half of the 68th Session was held at the Royal Society or Arts, Adelphi, London, W.C.2, on Thursday, January 12th, 1933, Mr. C. R. Fairey (President) in the Chair.

The President: Although the year 1933 was already ten days old, so far nobody had written a book to say that airships were no good. This subject, he continued, had been discussed and well ventilated on various occasions by the Society, and although every form of transport, and indeed every form of progress, aroused in certain people opposition and antipathy, that directed against the airship always seemed to him to be the most virulent. Despite this, however, the airship was still with them and promised to be with them even more in the future; its advocates were more enthusiastic and certainly appeared to be more able than its critics.

Squadron Leader Booth would be remembered perhaps best as having been in command of the *R.*100 on her double Atlantic crossing in 1930, but there were other facts with regard to Squadron Leader Booth which were of great interest. When he was transferred from the Royal Navy in 1915 he went to the R.N.A.S. (Airship Section); he commanded the *SS.*1, the *SS.*12 and the *C.*4 airships from 1915 to 1916, he was the First Officer of the *R.*24 in 1917, and was in command of the Airship Station at Mullion in 1918. After that, from 1920 to 1924, Squadron Leader Booth was a member of the Inter-Allied Aeronautical Commission of Control, and subsequently he was the First Officer and Captain of the *R.*33. In addition to all this, Squadron Leader Booth was a qualified aeroplane pilot.

Squadron Leader Booth: Before giving his lecture he apologised for the non-arrival of the film from America which had been promised him by the Goodyear Zeppelin Corporation. This film, he said, had been despatched from Akron about a month ago, but had been held up in New York for three weeks, and now could not possibly arrive in time for the Meeting. Therefore, he would have to be satisfied with illustrating the portion of the lecture to which this film applied with a few slides. After the lecture, however, Colonel the Master of Sempill had kindly offered to show a film which he himself had taken during his recent South American flight on the "Graf Zeppelin."

AIRSHIP DEVELOPMENT ABROAD

BY

SQUADRON-LEADER R. S. BOOTH

Last year I was fortunate enough to visit Germany and America at the kind invitations of Dr. Eckener and Admiral Moffett, and I hope that a short description of the development abroad will be of interest.

I propose to devote the short time at my disposal to these two countries, as, although France is still building non-rigid and semi-rigid airships for naval work and Russia has embarked on a most extensive airship programme, I think that the recent developments and improvements of the rigid type airship will be of more interest.

Germany

At the end of the war about 14 naval airships were in commission, but these were naturally of no commercial value, and, with other war material, were immediately handed over to the Allies either as scrap or as complete airships, which were subsequently delivered by air. The Zeppelin Company, however, had a highly-skilled staff and many employees, so work on a commercial ship was immediately put in hand. This ship was called the " Bodensee," and it was actually constructed in 21 days. This seems almost impossible, but it must be remembered that some of their largest ships were completed during the war in six weeks.

The " Bodensee " was completed and flying by August, 1919, and from August to December she carried out 103 flights, of which 78 were between Friedrichshafen and Berlin—a distance of about 450 miles. Altogether some 2,400 passengers and 35 tons of freight were carried on this route, but in December further flying was prohibited by the Allies, and she was handed over to Italy as " war material " in 1921. A sister airship named the " Nordstern " was not completed until airship flying in Germany was stopped, so that she never flew until 1921 when she was surrendered to France.

This was naturally a blow to the Zeppelin Company, but the staff and a nucleus of the employees were kept busy on the manufacture of agricultural machinery, aluminium castings, tanks, etc., until 1922, when approval was given for a new airship to be built for the American Government as reparations for the ships wilfully destroyed by their crews at the end of the war. Work on this ship was put in hand in 1922, and she would have been completed in 1923 but trials were delayed until the summer of 1924 by the non-delivery of the new 12-cylinder 440-h.p. Maybach engines. These were of an entirely new design and were the first of this famous type which has since proved to be the most reliable airship engine yet produced. All engines were reversible and fitted with roller bearing main bearings and big ends.

Trials of the new airship, or the " Los Angeles " as she was christened on arrival in America, were completed by the autumn of 1924, and many sceptics wondered whether she would make the Atlantic crossing, which meant a flight of 5,000 miles, or a world's record, if successfully accomplished. As we all remember, the flight actually lasted just over 100 hours, and on arrival over New York over 30 hours' fuel still remained on board. The " Los Angeles " was then handed over to the American Navy, and I shall touch on her subsequent history later on in this paper.

Dr. Eckener and his crew then returned to Germany, and, as a result of his enthusiasm and energy and the great belief of the German people in the future of airships, he managed to obtain enough public and government support to build another airship with which to demonstrate the commercial possibilities of this type of aircraft. The construction was started in 1927, and the airship was completed in 1928. The general details of this airship, which was christened " Graf Zeppelin," are as follow:—

Capacity	4,000,000 cu. ft.
Length	775 ft.
Diameter	100 ft.
Fineness ratio	7·75
No. of engines	5
Maximum speed	80 m.p.h.
Cruising speed	70 m.p.h.
Efficiency (or disposable lift—total lift)	50 per cent.

Actually about 25 per cent. of the hull volume is filled with gaseous fuel or " Blaugas "—This fuel is of the same specific gravity as air and is slightly more

efficient than petrol. From an airship point of view, it has a further advantage that there is no change in equilibrium as fuel is consumed. This is of the utmost importance when making oversea flights to poorly equipped bases, as the minimum of hydrogen is required to replenish the airship and the gas fuel is only slightly more expensive than petrol. Owing to the high efficiency of this airship, the range at cruising speed with 20 passengers on board and five tons of freight is approximately 6,000 miles. The external appearance of the " Graf Zeppelin " is quite well known to the British public, as she has visited this country every year since 1930—landing once at Cardington and five times at the London Flying Club, Hanworth. The interior arrangement is probably not so well known, and the next few slides will give a good idea of the passenger quarters and cabin arrangements. Twenty berths are provided, which can be turned into sofas during the day time. The kitchen, though small, can, however, produce meals equal to the best traditions of the famous Kürgarten Hotel, Friedrichshafen, which is responsible for the catering, as I am sure all who have been fortunate enough to dine on board will admit. Her achievements are also not so well known, as her flights have ceased to be " news " value owing to the monotonous regularity with which they are carried out. In fact it is quite difficult to find out whether she has arrived at her destination, even if her departure happens to have been mentioned in a sub-paragraph under News from Abroad. This is, however, a good indication of the safety of airship travel of the present day.

Before leaving this ship I think that a résumé of her flights should be placed on record.

In the summer of 1929 she flew round the world in 310 flying hours, or a total time of 20¼ days, including stops. The route was from Friedrichshafen via Tokyo, Los Angeles and New York back to Friedrichshafen, a distance of 21,000 miles. Up to date the " Graf " has crossed the Atlantic 31 times, and the Pacific once. She has made 13 cruises to South America, and return, of which five were extended to Rio, where four landings have been made and passengers embarked and disembarked. The average time taken for the flight to South America is 71½ hours, and 86 hours for the return, and the estimated times when preparing the timetable were 72 hours and 96. Last year the programme of South American cruises was punctually adhered to, with the exception of two departures from Friedrichshafen which were delayed 24 hours due to lack of ground handling facilities. On these occasions the return flight was made according to schedule. She has also flown to Egypt and Palestine and made a four-day exploration cruise in the Arctic up to a latitude of 82°N.

The summary of her achievements to date is 290 flights and 111 landings to an untrained landing party away from Friedrichshafen, 330,000 statute miles flown in 5,370 hours (an average of just over 60 m.p.h.), 8,000 passengers carried and 55 tons of mail and freight, and on the last return flight from Pernambuco 40,000 letters were carried.

It is interesting to note that the original gasbags are still in the ship, and of the original cover only small replacements to the bow and stern have been made.

Her programme for this year is fifteen flights to South America, with a possibility of landing at Barcelona and Seville, and an extension of the service to Rio. When the new ship is completed a weekly service will be established, and it is hoped that an air mail subsidy will be paid by the South American Governments when these two airships are in commission, and there is also a possibility of a shed being erected at Rio and also one at Seville.

The new airship just mentioned is now under construction at Friedrichshafen. The original capacity of 6,000,000 cu. ft. was increased to 7,000,000 after the *R.*101 disaster in order that the airship could be inflated with helium without loss of pay load. The leading dimensions of this ship are as follow:—

Total gas volume	7,000,000 cu. ft.
Length	813 ft.
Diameter	135 ft.

This gives a fineness ratio of 6.02, as compared with 5.34 for *R.*100 and 5.9 for *R.*101 after the insertion of the new bay. If the engines are ready in time she will be equipped with four 1,000-h.p. Diesel type engines, and it is hoped that a cruising speed of 80 m.p.h. will be obtained. The alternative to the 1,000-h.p. engines will be four tandem units each fitted with two 560-h.p. Maybach petrol or gas fuel engines. To avoid valving helium to compensate for the weight of fuel consumed, it is proposed to fit hydrogen gasbags inside the helium bags so that hydrogen gas would normally be valved, but if the ship is carried up in a vertical current it is understood that only the inert helium gas will be discharged. Accommodation for 50 passengers is being provided, the passenger quarters being inside the hull, and the general arrangements not unlike that fitted to *R.*100. To increase the comfort of passengers on long flights, shower baths will be provided, the water thus expended being pumped back into the ballast tanks. It is hoped that this airship will be finished next summer, or the following spring, and it will be of the greatest interest to compare her performance with that of the " Akron " and " Macon," as these airships will be all of approximately the same size but will have the fundamental difference that the " Akron " and " Macon " are built with deep section stiff rings similar to the *R.*101, but the new German airship has braced rings and an axial girder like the *R.*100.

This brings the development of German airships up to date, and shows an increase in size of passenger ships since the war from one to seven million—an increase in range from about 1,000 miles to 6,000, and an increase in paying load from 15 to 50 passengers, with a corresponding increase in freight. As only five ships, one not yet completed, have been designed since the war, surely this is a remarkable achievement.

America

I will now turn to American airship history. In that country only three rigid airships have ever been built, and one of these is not yet completed. The first ship, the " Shenandoah," was a copy of a German war type which was built for high altitude bombing raids. Naturally, the weight of the structure had been reduced to a minimum, and the risk of failure in the air correspondingly increased. As will be remembered, this actually happened in a severe storm encountered when on a cross-country flight to the Pacific coast, and a high percentage of the crew was lost. Before this disaster overtook her, the " Shenandoah " had made many notable flights from Lakehurst (including one to the Pacific coast), several to Bermuda, and had also been extensively used for mooring-out experiments and the training of airship crews. As, however, the new German airship, the " Los Angeles," had arrived at Lakehurst the previous year, airship development work continued, and this faith has been justified by the achievements of the last few years.

The " Los Angeles " was actually in commission for eight years, and during this period she was constantly employed training airship officers and crews, and also carrying out extensive experiments. She was put out of commission last July for reasons of economy, and on inspection the hull was found to be in excellent condition, and it may be noted that about 50 per cent. of the original cover is still on the ship.

Her record during this eight years' commission is briefly as follows:—

Total number of hours flown	4,350
,, ,, ,, ,, moored out	2,080
,, ,, ,, flights	339
,, ,, ,, miles flown	200,000

The total number of American naval officers trained must now be nearly 100, and as the majority of these are now with the Fleet it is obvious that the American Navy is being educated up to the use of airships.

The latest American airship, the "Akron," constructed by the Goodyear Zeppelin Corporation, with Dr. Arnstein as Chief Designer, was completed towards the end of 1931. As already mentioned, the hull is constructed of deep section unbraced transverse rings joined by 36 longitudinal girders. Other notable features are the internal engine rooms, swivelling propellers, water recovery apparatus and the internal aeroplane hangar. But perhaps the most important innovation is the construction of the gasbags, which in this ship for the first time on record are half of a synthetic skin substitute and half of rubber-proofed fabric. The use of gold beaters' skin is thus dispensed with, which reduces the cost considerably, and it is also hoped that the life of the bags will be prolonged.

The general dimensions are as follow:—

Capacity (total)	6,850,000 cu. ft.
Length	785 ft.
Diameter	133 ft.
Fineness ratio	5·9
Number of engines	8
Cruising speed	65 m.p.h.
Maximum speed	82 m.p.h.
Efficiency	40 per cent.

From a naval point of view, the aeroplane hangar and the development of the methods of hooking on and housing the machines are of special interest. This evolution was first practised in this country in 1925, using a D.H.53 aeroplane and a trapeze bar slung from *R.*33; it has been further developed in America, and a special bar similar to that fitted to the "Akron" was used on the "Los Angeles" for the training of pilots. The Akron is, however, the first ship with an internal aeroplane hangar, and actually five single-seater machines of 25 ft. 6 ins. span and length 19 ft. can be accommodated. The gear on the aeroplane consists of a propeller guard and a controlled hook which can be tripped by the pilot. Pilots quickly get the knack of making successful "landings," and I have actually witnessed over 100 landings being made on one short flight without incident—and half these landings were by pilots under instruction who had never hooked on before. If their machine is then required to be brought inboard the bottom hatches are opened and the trapeze bar hauled up by an electric winch; the machine is then transferred to a corner of the hangar on an overhead runner and the trapeze bar lowered for the next machine. From hooking on to being secured in the hangar takes approximately three minutes, so that five machines could be housed in about 20 minutes. The normal procedure is for the airship to leave the ground with the hangar empty; the aeroplanes leave the ground at the same time as the airship and are taken on board as soon as the correct height is gained. Up to date some 400 landings have been made to the "Akron," both by day and night, and it is customary for mails to be brought on board and landed by this method, and also for high officials to be landed from the airship if their duties do not permit them to remain on board for the whole flight. The whole evolution is definitely out of the stunt class, and the machines thus carried could be used for protection or scouting—and, in commercial airships, for landing or taking on board passengers or goods from intermediate stations where ground facilities for landing airships are not available.

Up to date, the "Akron" has flown for about 1,500 hrs., including a flight to the West Coast early last year. She has proved herself to be very handy in the air, and the new features such as the swivelling propellers, panel water recovery, radiators, etc., have given little trouble.

When the " Akron " was under construction, the question of ground handling was seriously considered and an entirely new system evolved which has proved to be so successful in operation that handling airships into the shed with a cross wind up to a maximum of 20 m.p.h. is almost an accomplished fact. We have proved in this country that airships can ride out gales up to 82 m.p.h. on the high tower without sustaining any damage, and as the Americans are on the high road to solving the ground handling problem, two of the fundamental airship handling problems are almost overcome.

The gear used for the " Akron " when being handled in and out of the shed is the ordinary transporter tower running on standard rail tracks, to which the bow cone is secured, and the stern is secured to a transverse beam 186 ft. long which runs on rails 65 ft. apart. The ends of the beam are secured by suitable bridles to the stern of the ship, the bottom fin being secured to the centre. Fore and aft tackles also secure the beam to the ship so that, as the airship is towed out of the shed, the beam maintains its correct relative position. The total weight of this beam is 90 tons.

A turning circle is provided just clear of the shed, the transporter tower stops in the exact centre of this circle, the stern beam is transferred to the circular track by raising one set of bogies and lowering another, and the stern of the airship is then swung down wind by a special locomotive. The airship is then ready to be walked over to the mooring-out circle or to leave the ground as soon as the beam bridles are disconnected.

Conversely, when entering the shed the airship is hauled round to the fore and aft line of the shed, after being attached to the beam, by means of the beam locomotive; bogies for the parallel tracks are then engaged and the airship walked into the shed securely held at both ends. The locomotive used is specially designed; it is powered by a 250-h.p. petrol engine and fitted with a Waterbury hydraulic variable speed transmission. The speed control is therefore extremely sensitive and a maximum speed of 7 m.p.h. can be obtained. The tractive force of this locomotive is 30 tons. I have actually witnessed the " Akron " leave the hangar with a cross wind of 10 m.p.h. giving a lateral load on the tail of nine tons, and as the stern fittings are designed for a lateral load of 24 tons, it will be appreciated that the ship can be safely handled in a beam wind up to 15 m.p.h., and winds of increasingly higher velocity as the direction approaches the fore and aft line of the shed. Handling an airship of this size without mechanical means would, of course, be absolutely impossible except in a flat calm, and I think that Lieut. Bolster, U.S. Navy, who originated the idea, is to be congratulated on the success of this scheme, which even in this country would make it possible to enter or leave the shed on about 300 days of the year. The great advantage of this system is its simplicity and the fact that there is practically no chance of any hold-up when entering or leaving the hangar, as has often occurred with the side runners as used in Germany during the war and also with the " Los Angeles " at Lakehurst. Further, the equipment is comparatively simple, as standard gauge lines can be used and the weight of the beam is sufficient for all side loads, so no special holding-down devices or expensive concrete foundations to support the rails against heavy side loads are necessary. The new beam now being built for the base at Sunnyvale, California, will have many improvements over the beam I have shown you on the slides, the chief improvement being the incorporation of the locomotive in the beam instead of having a separate unit.

Considerable progress has also been made in the design of transporter towers; the original one was fitted with caterpillar tracks but these were not very satisfactory, due to the unevenness of the aerodrome. The new tower for the " Akron " was therefore fitted with four-wheel rail bogies, and the tower now under construction will also be telescopic. The advantages of the high and low towers will thus be combined in one structure, and the possible danger of trans-

ferring from a high to a low tower before going into the shed is eliminated. The telescopic tower will normally be extended to its maximum height—160 ft.—for landing and leaving, so that a tail-down landing can be made and the take-off will also be facilitated. When moored, the tower will be telescoped and the after car, or tail plane, secured to a rail trolley running on a circular track. Up to date, this system has proved to be quite successful for normal conditions, but it is still questionable whether the low tower is as safe as a high tower in really strong gales such as are experienced every winter in this country. In Sunnyvale such conditions are, however, never experienced, so the telescopic tower and stern beam should meet all requirements and ensure that the ship is never weather-bound in the shed when fleet operations are in progress.

The base at Sunnyvale will be completed early this year ready for the "Macon," which will be completed in the early spring. The "Macon" is almost identical to the "Akron"—swivelling propellers, water recovery, aeroplane hangar, etc.—but minor alterations and improvements have been made which will give her a slightly better performance, also all the gasbags will be of gelatin-latex proofed fabric, as bags of this type fitted to the "Los Angeles" and "Akron" have proved to be very satisfactory in service. When the trials are completed, she will proceed direct to Sunnyvale for fleet co-operation work. This will be the crucial test of naval airships, as the "Akron" has never had the opportunity of working with the fleet, and the "Los Angeles" was unable to do so—except on one occasion—owing to the agreement made when she was handed over by the Germans.

This concludes the brief résumé of rigid airship development in America, but before terminating the paper I should also like to mention the work done by the Goodyear Zeppelin fleet of Blimps during the past few years, and also the development of the Metalclad airship. The Blimps have now made over 32,000 flights, carried over 80,000 passengers, and flown over 1,000,000 miles—and have visited practically every State in America. Last year one flew from Akron to Los Angeles by easy stages. They are extremely easy to fly, as the pressure control is entirely automatic, and if the revenue from the passengers carried is taken into consideration, they must prove to be a very cheap and effective form of advertising.

As regards the Metalclad airship, I am afraid little progress has been made since Mr. Fritsche read his most interesting paper before the Royal Aeronautical Society two and a half years ago. The original ship is still flying, and on deflation last spring no deterioration of the hull could be found. The gas consumption is extremely low and, although lively in the air in bumpy weather, she is very sensitive on controls and easy to handle. The Metalclad Airship Corporation has projects for ships of two and five million cubic feet, and if given the opportunity there is little doubt that satisfactory ships would eventually be produced. The trouble is that nobody has any money to build the conventional type, and it is doubtful if any new commercial airship company would have enough courage to back such a revolutionary change. It is the greatest pity, as, if airship development continues, the Metalclad may possibly prove to be the most efficient type. Builders of airships dare not, however, experiment nowadays, as any failure completely overshadows years of successful operation.

I have now briefly outlined airship development in Germany and America. In America two naval ships of 7,000,000 cu. ft. displacement will soon be operating with the fleet from a modern airship base, and from Germany two ships will be flying on a commercial route.

The governments and financiers of the world will then have an opportunity of reconsidering their attitude with regard to future airship development.

In conclusion, I should like to express my thanks to the Air Ministry for the permission to read this paper to-night.

Discussion

THE PRESIDENT: Everybody greatly appreciated the trouble Squadron Leader Booth had taken in preparing his lecture, and also the exceptionally lucid manner in which it had been delivered. Before asking for discussion upon the lecture, however, there was to be an interesting interlude. As Squadron Leader Booth had mentioned, the film which it had been hoped would have arrived from America had gone astray, but a Past-President of the Society, Colonel Sempill, would show an interesting film which he himself had taken. At the same time, Colonel Sempill was anxious for it to be explained that he did not pose as an expert cinematographer, but was merely showing the results of his amateur efforts.

THE MASTER OF SEMPILL: That evening would be remembered for many reasons, one of them being that they had been addressed on the subject of airship development abroad by 50 per cent. of the existing British airship personnel, because Squadron Leader Booth and Major Nixon, from Cardington, were really the only people in this country watching this matter from the standpoint of the Government. That was what they had descended to after the wonderful work they had done in past years.

As to the " Graf Zeppelin," he would like to make a few observations upon life on board this airship from the technical point of view. It had been peculiarly interesting to him to have lived on, and had the run of, the ship for ten days in November last, during a cruise to South America and back, and to have seen just what condition she was in after five years of very active service. As had been said in the lecture, the " Graf Zeppelin " had flown some 5,500 hours; but apart from minor details mainly relating to the decorating of the passengers' cabins, there was virtually nothing requiring attention. A few days ago he had looked into the insurance situation with regard to the ship and found that the total claims that had been made during those years' operations had amounted approximately to 1,500 Rm. The bulk of this amount was for loss of gas incidental to a trip to Russia when some ill-disposed persons fired at the ship during the night and caused leakage from the after gasbags.

With regard to the outer cover and gasbags, some 60 to 65 per cent. of the original remained; there had only been certain minor alterations in the method of securing the outer cover.

As giving some idea of the permanency of the organisation, it was interesting to find that Herr Marx, who was coxswain on the first ship launched by the Zeppelin Company in 1900, was still in the service of the Company and frequently acted as coxswain of the " Graf Zeppelin."

With regard to the question of finance, it could be taken that on the present services to South America expenses were being covered by revenue obtained from passengers and mails. They were not yet able to operate this service throughout the whole year, but under the arrangements now being made for the construction of a hangar at Rio de Janeiro, and one in Spain, a regular yearly service should soon be possible.

From the point of view of further development of the German airship services, the situation was that towards the end of the present year the " Hindenburg " would run her trials. This ship had been fitted for accommodation for some 50 passengers, but the number might be increased to 75. She was originally designed for the North Atlantic service in conformity with certain arrangements made with those interested in the development of civil airship services in the United States of America. Owing to the financial difficulties in that country the programme had received a temporary set-back, and it might therefore be necessary to run this airship on the South American route.

So far as the United States was concerned, as the lecturer had said, the " Macon " was to be launched in about six months' time, and if the conditions

were then suitable financially, the intention would be to lay down a ship for civil work in the dock at Akron. Whether that would actually be done, however, it was impossible to say at the moment.

The idea was that airship development from the civil standpoint could only be achieved on a truly international basis. At the present moment Germany and the United States were working together, but it was hoped that those who were interested in airships in this country would be able to awaken sufficient interest and make it possible for us again to participate in this development. In this connection the point he wished to emphasise—and he knew he would be supported in it by Squadron Leader Booth—was that Dr. Eckener and the entire staff of the Zeppelin Company were anxious to do only one thing, and that was to achieve success in the development of airships and to assist us in every possible way.

Wing Commander T. R. CAVE-BROWNE-CAVE: He very much doubted whether the extent of foreign airship development was quite realised, even after hearing the lecture. Personally he had been out of airship work for some two years, and during that time had had very little direct airship news. He was therefore well able to compare what the lecturer described as having been done with what was thought probable two years ago. It was clear that achievement had gone ahead of expectation to an astonishingly great extent, and the achievement had been most remarkable. It had to be remembered that when Squadron Leader Booth lectured, as he had done that evening, he did so in a thoroughly characteristic manner, making pure statements of fact which had come under Squadron Leader Booth's own personal observation. There was no speculation of any sort or kind.

It was interesting to see how development had taken place, mostly along lines which those concerned with airships had thought were probable; the development of mooring and handling being one of the most important features. One of the more unexpected things was the development of the small non-rigid airship. At the end of the war they in this country were well ahead of others in the design of non-rigid airships, but it was generally agreed that for peace purposes this type had very little application. It was interesting to see how America had developed this type, very much on the lines that we had originated in this country, and was making such astonishingly good use of them. Personally, when at such meetings, he almost automatically took the engine point of view. He could not now help feeling that, so far as engines are concerned, foreign nations had almost reached the point achieved in 1930 by this country in the development of the heavy oil engine for airships.

Dr. ROXBEE COX: One thing which had struck him was the contrast between the arrangements for ground handling at Akron and at Pernambuco, and it would be interesting to have the lecturer's opinion of the Pernambuco arrangement. Although the latter seemed delightfully simple, it would be interesting to know whether a ship could ride out in really bad weather on a stub mast and a simple trolley of the kind illustrated. Also he would like to know whether the 15-miles-an-hour wind which had been mentioned as the maximum in which the handling arrangements at Akron could be used could be regarded as a satisfactory maximum. In this country, it had been pointed out in the lecture, that even with this wind speed restriction an airship could be handled in and out of the shed on 300 days out of 365, but was that sufficient for an airship in regular service? Personally he should think it would not be. On a regular service it would be undesirable to run the ship constantly in and out of the shed. It would, therefore, be necessary for it to moor in the open, and it seemed to him that the high mast was still the best way of doing it. He had left airships some time ago, however, and so may be out of date. Consequently he would like to know Squadron Leader Booth's opinion as to the relative values of the high mast and the Pernambuco mast arrangements in riding out bad weather. The telescopic

mast at Akron was not intended, he presumed, to be used for riding out but to facilitate ground handling operations.

Another point was the value of swivelling propellers in landing. When Squadron Leader Booth was in America no doubt he seriously considered this matter. Personally he had some doubt as to whether these propellers could exert sufficient thrust to be as efficient in practice as ballast operations. The bevel gearing with which they were driven involved a certain loss of power, and it could only be assumed that the Americans had decided that that loss was more than compensated for by the decrease in head resistance with the internal engines. However, were the Americans still of that opinion and did they believe that the difficulties which presumably they had had with their internal engine room and bevel gears had really been worth it?

With regard to Wing Commander Cave-Browne-Cave's reference to blimps, and the Goodyear Zeppelin Company's use of them for advertising, he thought it should be placed on record that in this country the Airship Development Company tried with a blimp the same sort of thing a few years ago. They deserved some credit for trying to do in less favourable circumstances what had been so successfully done in America.

Mr. E. F. SPANNER: He could only hope that he would be given an opportunity later on of attending another lecture before the Society dealing with the progress of airships in the service of the British Empire. His own feeling had always been that the airship has very little value for passenger service, but that it could be utilised with advantage for carrying mails. Such criticism as he himself had at times directed against airships had been on technical grounds. So far as the design of the " Graf Zeppelin " was concerned, he had always felt satisfied that this type would achieve something of the measure of success that had actually been the case. The lecturer was quite right in referring to the danger of making a single mistake in developing airships, and there was little doubt but that those who had the interest of airship development at heart must go ahead and build up soundly on what had been done already. Squadron Leader Booth and Major Nixon had an important task to carry out in watching and reporting on developments abroad. There was little doubt but that they would adequately fulfil the duty which had been placed upon them, by coming back with information such as had been given that evening. As a result of their work it was to be hoped that we in this country should be in the position, later on, of finding sufficient commercial support for some scheme for developing airships along lines of practical service. Such commercial schemes would not, at any rate, receive any technical criticism from himself.

Captain BOOTHBY: One of the most striking statements made in the lecture was that the American Navy has 100 trained airship pilots actually afloat with their Fleet. It could be said that the British Fleet has not one single officer with it who had had any experience of airships, which was a very bad state of affairs, because the British and American Navies were supposed to be on a parity. When it was remembered that airships could be built in six weeks and could be manned at once in America, whereas even if they could build them—which they could not—they could not possibly man them, it was obvious that the state of parity of the two Fleets was not what it seemed on paper. In Squadron Leader Booth they had the only airship pilot in the British Empire who was really up-to-date. There were a few others who could be brought up-to-date if they could only give them a refresher course, but they could not do this because there were no airships in which to give them such courses. Nobody had been trained in this country since the war; the Admiralty could not, and the Air Ministry did not, do so; and therefore it was up to somebody else to try and do something about it. He suggested that private enterprise should step in and see if something could be done to form a school for training British airship pilots.

The scheme for hitching aeroplanes on to airships would undoubtedly lead to great developments in the Fleet. Our cruisers were being fitted with catapult launching gear for aeroplanes, and it was necessary for the aeroplanes to come down on to the sea and be hauled on board. This reduced the possibility of using aeroplanes by our Fleet, as they would only operate when the state of the sea permitted, whereas a few moderate-sized airships carrying a few aeroplanes could accompany the Fleet, and these could be got away and taken in again at any time. It was to be hoped that the lecture would help to draw attention to the possibilities in this direction, and if it should lead to the abolition of the present aircraft carriers a great saving of expense, with a gain in tactical efficiency, would follow.

Mr. J. L. Hodgson: Could the author give further information concerning airship development in Russia? It was not clear from the lecture whether the Russian airships were to be of the rigid or of the non-rigid type. He believed that Russia was going in for a large programme of airship construction, and it would make the lecture complete if a brief account could be given of those developments.

Further, could the author give any information as to how the transporter mast and the travelling beam which he had described were used, and how they were maintained at the same speed so that one did not overtake or pull away from the other and so strain the ship?

Again, was it possible to have some particulars of the gelatine latex which was being used instead of gold beater's skin?

The thing he really wished to say, however, continued Mr. Hodgson, concerned the closing remarks of the lecturer with regard to there being no money available for airship development. Twelve months ago, in the same lecture room, he himself had read a paper* before the Royal Society of Arts in which he had commented upon their curious economic system which produced so many technical achievements and opened up the way to such an immense potential plenty, yet left them with no money to carry out their experiments on airships and kept large sections of the population in dire poverty. As a result of his own thought, he had come to the extraordinary conclusion that every economy produced by engineers was, under the existing system, immediately balanced by an equivalent communal waste, such as unemployment, rationalisation, foreign trade in which goods were exchanged for gold or bonds, sabotage of raw materials, and so on. The system could be likened to a tank into which engineers, scientists, and organisers pumped efficiencies, whilst another set of people produce leaks in the tank which were as nearly as possible equivalent to the efficiencies that had been pumped into it. Therefore, it was up to engineers who wanted to get things done to study this curious economic system more closely, to understand how the leaks occurred and then to stop them.

Squadron Leader Nixon (Superintendent, Royal Airship Works, Cardington): The lecturer has drawn attention to the increase in size of the airship up to the present time; the latest airship, *LZ.*129, being 7,000,000 cu. ft. capacity. The sizes mentioned show that the airship designer has the important fact of improved performance always in view. Yet one is inclined to the conclusion that the craze for elaborate passenger accommodation to rival the large ocean liner is responsible for visualising airships of 12/15,000,000 cu. ft. capacity, although very eminent authorities state that such sizes are within the scope of aeronautical knowledge.

Would it not be better to call a halt and concentrate on a standard size of, say, 7/8,000,000 cu. ft. capacity, with a cruising speed of 75/80 m.p.h. and a pay load of 15/20 tons over a range of, say, 4/5,000 miles? This would allow

* "Some Aspects of the Problem of Industrial and Commercial Waste." Journal of R.S.A., February, 1932.

the designer to concentrate on improved performance by attention to girder structure, gasbags and outer cover, and passenger accommodation of not too elaborate a nature.

He can certainly rely on improved performance from the development of the aircraft Diesel engine.

With simpler passenger accommodation for a limited number, say 50, this would allow adequate provision to be made for mail and freight.

When the demand for more passenger and mail accommodation is apparent, an increased number of airships with more frequent sailings could be provided.

The question often arises, with the development of air lines by aeroplanes and seaplanes throughout the world, why airships are required; but on examining the air lines in operation, it is observed there is no through air communication from Europe to America, nor from America to Japan and China—the most important trade centres of the world.

The flights carried out by the "Graf Zeppelin" to South America, he thought, gave adequate proof of the suitability of the airship for these long over-sea routes.

If this service had to be carried out by the large seaplanes, such as the *Do.X*, at least six sea aerodromes, including two in mid-Atlantic, would have to be established to permit of the same commercial load being carried, against only two bases required by the airship. He referred to this because the cost of the ground organisation is often mentioned by airship critics. He could say very definitely that the cost of the ground organisation on such routes is very much in favour of the airship, even when sheds in addition to mooring towers are provided.

No one would be bold enough to venture the opinion that seaplanes will never be a success on these routes, but even if they do succeed in the future, Dr. Eckener deserves full credit for the great effort he is making to establish the first through air line between Europe and America.

Even if supplemented or superseded by other forms of aircraft in the next decade, the airship will have at least played its part in bridging over the intervening period.

Mr. PYE (Deputy Director of Scientific Research): He presumed that the "Graf Zeppelin" had been operating as a hydrogen ship, but it would be very interesting if Squadron Leader Booth, or the Master of Sempill, could say if the future plans of the Zeppelin Company contemplated a change over to helium. If that was the intention, could it also be said how the supply of helium was envisaged?

Another point which had occurred to him was that not much was heard about the operation of the fuel gas in the "Graf Zeppelin." It had been stated in the public press that the next Zeppelin contemplated was one which would be driven by heavy oil engines; in other words, it was proposed to give up the Blaugas, which had always appeared to him as a very effective way of preserving the lifting gas. Perhaps, however, either Squadron Leader Booth or the Master of Sempill could throw some light on the point of how completely successful the use of Blaugas had been, and whether it was thought that the heavy oil engines that were said to be contemplated would give an equally light power plant, in which term he included the weight of the engines and the fuel. Finally, there was the question of the weight of the power plant in the "Akron," with its long shafts and bevel gears involved in the internal engines driving external airscrews. There had been some speculation about the extra weight involved in this scheme, but now it must be a matter of fact as to what extra weight (expressed as lb. per h.p.) is involved in carrying the driving shafts out through the envelope.

Squadron Leader GODDARD: He would like to draw attention to a point in the lecture which he regarded as of great importance in estimating the future

performance of the new German and American airships. The latest American airships, as had been pointed out, were designed rather on the lines of the Committee-designed ship *R.*101, whereas the new German ship follows very much the original design of Mr. Wallis. In saying that the future of airships could be gauged by the performance of these two classes, it would be interesting to bear in mind that it was really a competition between *R.*100 and *R.*101 again. At any rate, that was one interpretation to be placed on the position, which should be kept well in mind because it was, he believed, generally in the mind of the British public that of the two types *R.*101 represented the greater technical achievement, although his own view was that this might be shown to be not quite so conclusive. Another point was that, from a long acquaintance of the lecturer, he knew he objected to any commendation, especially from his friends, but what Squadron Leader Booth said was usually, if anything, a little bit less—indeed a good deal less—than what might be said. Therefore, whatever he said was absolutely reliable.

Mr. G. F. MEAGER (Associate Fellow): Squadron Leader Booth states that the covers of the " Graf Zeppelin " and the " Los Angeles " are still partly the original covers. To what may this longevity be attributed, as his experience with the covers of both *R.*100 and *R.*101 was that they required renewing before the airships had been in commission twelve months? Was this due to difference in material, superior design, or to meteorological conditions?

In regard to gasbags, too, the " Graf Zeppelin's " bags seem to have stood up to their work much better than was their experience with those in *R.*100, although he believed they were manufactured by the same firm. In addition, there is no comparison between the flying time carried out by both airships—the " Graf Zeppelin " having done ever so much more than *R.*100. It therefore seemed to him that there must be some connection between the inferior outer cover and the comparatively short life of *R.*100's gasbags.

Of course the different method of housing the bags in the airship may be another factor in the varying length of life of the bags, and also the care taken of the bags when stored or not in use.

Another item in Germany and U.S.A. which does not seem to have been the bugbear they found it, is corrosion of the duralumin, though he believed the worst and in fact most of the corrosion experienced in *R.*100 was caused by the use of " Vellumoid " packing. Is there any difference in the composition of duralumin as made in Germany and America and that made in England, or can their corrosion be put down to different methods of treatment during manufacture? Perhaps methods of storage may also have something to do with the matter.

A most interesting part of the lecture was that part of it that dealt with the aeroplane arrangements, one noticeable feature being that the aeroplanes are not taken off the ground by the airship. As the " Akron " is for use with the fleet, is it proposed to carry out any hooking-on experiments with seaplanes or flying boats?

Mr. T. S. D. COLLINS (Royal Airship Works): One of the most important features of airship development abroad is the substitution of helium for hydrogen as the lifting medium. At the same time, it is also of importance to note that the magnificent performances of the "Graf Zeppelin" quoted by the lecturer have been made with the use of hydrogen. Now, although the change from hydrogen to helium has been made for one very good reason, they in this country who are interested in the future of the airship ought not to forget the several advantages possessed by hydrogen in comparison with helium, advantages which, in his opinion, outweigh its one disadvantage. The most obvious of these advantages is its lower density and consequent greater lift. As an example of this, the airship " Akron," if inflated with hydrogen, would have an increased lift

of 18 tons. This is surely of great importance, not only from the commercial aspect but also from the point of view of safety in operation. Again, for this country—if not for most countries—the production of hydrogen on the large scale required for airship purposes is much cheaper than the acquisition of helium from elsewhere; in fact, from the commercial standpoint, the cost of transportation of helium in large quantities would be prohibitive. Yet another advantage of hydrogen is its high calorific value as a fuel. If hydrogen could be burned in a suitably-designed airship engine, as he believed it could, the large waste of gas which necessarily occurs on a long voyage would be avoided.

The lecturer has given a very admirable account of the development of mechanical handling appliances in the U.S.A. It would be of interest to know if the use of a transporter tower, stern beam, locomotive, bogies, rail tracks, and other equipment for dealing with cross-wind forces on an airship is more efficient and less expensive than a revolving airship shed with which an airship could always be taken out or housed in the direction of the wind and cross-wind forces would be eliminated. The idea is not a new one, since revolving sheds have been used in Germany. If the problem of making a large airship shed revolve is not impossible of solution it would seem that with a very simple towing arrangement an airship could be handled in winds of much higher velocity than is possible with the equipment described. There would also be the added advantage that special strengthening of the airship's structure to withstand side loads would not be necessary.

Reply to Discussion

Squadron Leader R. S. Booth, replying to Dr. Cox, said that in his opinion the low mast at Pernambuco was quite adequate, as Pernambuco is in the trade wind belt where winds over 40 m.p.h. are hardly ever experienced. He concurred that the high tower was still essential in countries such as England, where winds up to 80 m.p.h. occurred every winter. As regards the telescopic tower, he understood that the full extension would only be used for landing and leaving the ground when the greater clearance under the stern would be an advantage.

Swivelling propellers undoubtedly facilitated landing these large ships, but he was still doubtful whether this advantage justified the extra weight, loss of power, and reduced reliability.

He was very gratified to hear that Mr. Spanner considered that airships could be utilised for carrying mails, as this admission from such a critic was a great encouragement to the airship enthusiasts in this country.

The question of Russian airship development had been raised by Mr. Hodgson, but he had no information beyond what he had read in the press, where it had been stated that 94 airships were to be built. These were to be of the non-rigid and semi-rigid type up to a capacity of 300,000 cu. ft., and he believed that two or three small airships had already flown.

Squadron Leader S. Nixon suggests that the size of ships should be limited and he agreed that with our present knowledge it should be possible to increase the disposable lift by increasing the efficiency instead of increasing the size of the ship every time a new one was built. Personally, he was of the opinion that mails were of greater importance than passengers at this stage—and infinitely easier to carry.

In reply to Mr. Pye, he believed that the new German ship would be operated on hydrogen if used on the South American route, but if this airship was eventually used on the North Atlantic route in co-operation with the Americans they might be forced to inflate with helium. He agreed that the use of Blaugas was a most effective way of conserving the lifting gas, and the achievements of the " Graf Zeppelin " could be largely attributed to this cause and also to the high efficiency

of this type of fuel. If inflated with helium, however, it would obviously be inconsistent to use this type of fuel, and heavy oil would take its place.

As regards the weight of the transmission shafts, etc., for the swivelling propellers, he believed that this is approximately 2.8 lbs./h.p., but this must be off-set by the reduced weight of the engine car and reduced air resistance.

In reply to Captain Meager, he believed that the covers of *R.*100 and *R.*101 failed due to the fact that they were pre-doped instead of being doped in place, and that the unsupported areas were considerably larger.

The gasbags in *R.*100 would have lasted as long as the " Graf Zeppelin's " if they had been kept dry, which was of course impossible with such a defective cover.

As regards corrosion, the German practice is to varnish all components, and the Americans anodise and then varnish. Both methods give good results. In this country he believed that, in the past, we had erred on the side of too much caution, and it is of interest to note that the corrosion of the remaining bay of *R.*100, which has been hanging in the shed for twelve months without any maintenance and is now over five years old, is still negligible.

As regards the attachment of seaplanes or flying boats to the " Akron," he considered that this could be done with the smaller type, but as these would not be seaworthy, the land type of machine is probably preferable.

He concurred with Mr. Collins and his views on helium. In his opinion, the fundamental requirements of airships were lift and reliability, and for commercial operation he considered that a hydrogen ship was probably safer than a helium one.

The suggestion that a revolving shed might be cheaper than the American ground equipment is of interest, but it is doubted whether this is actually the case. Even with a revolving shed a transporter tower would be necessary, so that, if the American system is considered, the only saving would be the cost of the stern beam, as the " hauling up " circle would still be required for the stern trolley when moored to the low mast.

NOTE ON THE APPLICATION OF BERRY FUNCTIONS TO THE DETERMINATION OF INITIAL STRESS

BY

W. E. DUMBRILL, A.R.C.S., B.SC., F.R.AE.S.

The purpose of this note is to point out that in certain simple cases an immediate solution of the problem of finding an initial stress is provided by an inverse application of the functions tabulated by A. Berry in his work on the generalised theorem of three moments.[1]

CASE 1.—Straight link of uniform section, pin-jointed at ends, with unknown axial compression P.

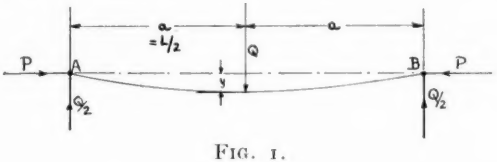


FIG. 1.

With the notation of Fig. 1, let a known force Q be applied at mid-span, at right angles to the axis of the pin-jointed member AB. Making all the assumptions of the theory of simple bending, it is easily shown[2] that the deflection under the applied load Q is

$$y \text{ (say)} = (Q/P) \{ (\tan na)/2n - a/2 \}, \text{ where } n^2 = P/EI \quad . \quad . \quad (1)$$

Equation (1) may be rewritten

$$y/Q = \{ (\tan na - na)/(na)^3 \} (a^3/2EI) = (\psi(\theta)/3)(L^3/16EI)$$

on putting $na = \theta$, and $a = L/2$.

Thus, the deflection per unit load, y/Q is, in the case of axial compression,

$$y/Q = (L^3/48EI)\psi(\theta), \text{ where } \psi(\theta) \text{ is one of the Berry functions.}$$

When $P \to 0$, $(\theta) \to 1$, and so the effect of the end load P is shown by multiplying factor $\psi(\theta)$. A. Morley, in his treatment of the end-loaded beam, expresses the effect of P by additive terms.[3] The advantage of the present method is that it, at least theoretically, enables us to determine the magnitude of P from the results of a deflection experiment, since, for a member for which E, I (both supposed constant) and the length L are given, $\psi(\theta)$ will be a function of P only; thus we may write

$$\psi(\theta) = f(P) = (48EI/L^3)(y/Q) \quad . \quad . \quad . \quad . \quad (2)$$

Substituting the value of y/Q (as given by the slope of the load-deflection curve) and the other quantities on the right hand side of equation (2) will give at once the numerical value of $\psi(\theta)$ and then reference to the table (with interpolation where necessary) will give θ, from which P readily follows.

As an example, let $EI = 15 \times 10^6$lb./ins.^{2}, $L = 120$ins. and suppose y/Q is found to be 0.02ins./lb.; then $\psi(\theta) = (48 \times 15 \times 10^6)/(120)^3 \cdot (1/50)$

$$\psi(\theta) = 8.33.$$

Roughly interpolating from Berry's table, $\theta = 84.5$ degrees $= 1.475^c$
$\therefore 60\sqrt{(P/EI)} = 1.475$ whence $P = 9{,}050$lb.

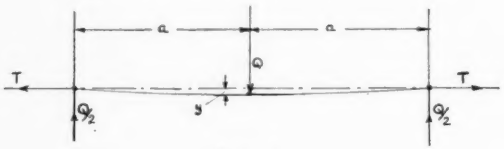


FIG. 2.

CASE 2.—Unknown tension T (Fig. 2). The equation for the deflection in this case follows immediately from equation (1) by putting $P = -T$ and replacing n by ni where $i = \sqrt{-1}$. We thus obtain

$$y = (Q/T)\{a/2 - (\tanh na)/2n\}$$

This may be rewritten

$$y/Q = (a/2n^2EI)(na - \tanh na)/na$$
$$= (l^3/16EI)\{(\theta - \tanh\theta)/\theta^3\}$$
$$= (l^3/48EI) \cdot \Psi(\theta)$$

where $\Psi(\theta)$ is Berry's function $3(\theta - \tanh\theta)/\theta^3$.

As before this reduces to unity for $\theta \to 0$, *i.e.*, for $T \to 0$.

NUMERICAL EXAMPLE.—With the same values of E, I and L as before let the measured deflection per unit load be $y/Q = 0.002$ins./lb. Then

$$\Psi(\theta) = (48EI/L^3)(y/Q) = 0.833.$$

Reference to the table now gives $\theta = 0.71$ approx.

$$\therefore 0.71 = 60\sqrt{(T/EI)} \text{ whence } T = 2{,}120\text{lb.}$$

As an alternative to using the tables prepared by Berry, the approximate expressions given later by H. A. Webb[4] may be employed if great accuracy is not required. These are

$$\psi(\theta) = (P_e - P/70)/(P_e - P),\ \Psi(\theta) = (P_e + P/80)/(P_e + P)$$

where P_e is Euler's crippling load for the member.

REFERENCES.

1 Transactions of the R.Ae.S., Vol. 1, Nov., 1919. Tables of the functions are also given in Pippard and Pritchard's "Aeroplane Structures," in the A.M. publication "A.P. 970" and elsewhere.
2 *E.g.*, J. Prescott. "Applied Elasticity," Art. 82.
3 "Phil. Mag.," June, 1908.
4 "Aeronautics," Jan. 1st, 1919.

CORRESPONDENCE

The Editor, JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—I have read Lieutenant Salt's lecture with a great deal of interest. He has covered the broad fundamentals of the subject thoroughly and at the same time concisely. I admire his ability as a writer, because I know from experience how difficult it is to explain and describe photographic surveying methods. I do not concur in all of his conclusions and recommendations and believe several eminent photogrammetric engineers have quite different views. The wide differences of opinion among students of this subject are to be expected, in view of the great differences in the basic map problems of different countries and territories.

Taking his lecture by paragraphs:—

1. *The Social Function of Air Survey*

I am confident nearly every experienced surveyor or map technician, who has studied the functions of maps, will agree whole-heartedly with Lieutenant Salt. From an article recently published in the *National Geographic Magazine* on the history of mapping, I concluded maps were appreciated more a hundred years ago than they are to-day. It appears to be a fact that executives in charge of big construction projects will shop the whole world over to save a few cents per ton for steel and at the same time hesitate to approve expenditures for mapping, which might influence the basic designs sufficiently to save many tons of the steel itself. In the case of steel, of course, the comparative prices indicate the amount saved; unfortunately the possible savings from map information are harder to determine, because so often no map is ever made; therefore, no comparison becomes possible. Furthermore, a conscientious engineer will hesitate to estimate in advance what saving any particular map will enable him to make.

I believe the difficulty in definitely determining the money value of maps, both present and future, is one of the major obstacles to be overcome before people can be brought to recognise their necessity. If Lieutenant Salt has data on more cases similar to the Gold Coast Railway, I hope he will publish it.

2. *Photography as an Aid to Survey, and*

3. *General Theory of Stereoscopic Pairs*

Lieutenant Salt's method of explanation is splendid.

4. *Plotting Machines*

Lieutenant Salt has been very clear in his description of internal orientation, external orientation and setting of scale and orientation of relief model. Other lecturers and photogrammetric technicians often divide these various operations (there are six separate steps) into simply two general operations: Internal and external orientation. Various authors use somewhat different terminology. Unless a student knows the writers' peculiarities in this regard, he may become confused.

I fear such eminent engineers as Henry Wild, inventor of the Wild autograph plotter; Dr. Hugershoff, who developed the aerocartograph; Dr. von Gruber of Zeiss-Aerotopograph, G.m.b.H., who designed the stereoplanigraph; and others, may question Lieutenant Salt's statement that the Fourcade stereogoniometer

is the only instrument constructed on fundamentally correct design. Theoretically, Lieutenant Salt is probably correct. It is a fact, however, that splendid maps are being produced economically with these other instruments and the recent application of the new Zeiss aerotopograph multi-lens camera to the stereoplanigraph promises not only to reduce costs materially, but to increase accuracy at the same time.

Lieutenant Salt points out the disadvantage of the high cost of these instruments. The cost is indeed high, especially in countries exacting import duties and often in addition royalties are assessed. One stereoplanigraph, together with the Zeiss four-couple camera, imported, set up and placed in operation in the United States, involves approximately $50,000. However, experience has proved instruments of this type have a long life, in fact they will probably be made obsolete due to some future invention long before they wear out. The carrying charges and necessary reserves for obsolescence are heavy, but by working the apparatus in shifts so as to keep it continuously in operation, my computations indicate the cost per unit of map produced will compare most favourably with the best of all other methods, in producing maps of a high order of accuracy or at the larger scales.

5. *Simplifications in Case of Vertical Photography*

I do not entirely concur with Lieutenant Salt's conclusions. Much depends upon the scale and accuracy of the map required. For the reconnaissance or semi-reconnaissance type of map, made at the smaller scales with considerable tolerances permitted, his method has many of the advantages claimed for it. However, as mapping specifications become more rigid and greater accuracy is required, I believe the automatic plotting stereoscope will unquestionably prove more efficient.

Let us review the advantages Lieutenant Salt enumerates. He claims:—

(1) *Simpler and cheaper equipment may be used.*

This is true and in turn permits quick and easy transportation, which should interest military men.

(2) *Film negatives and paper prints are normal, with correspondingly simpler air photographic problems.*

I cannot agree. The modern plotting machines use film successfully. Paper prints are not even essential, although they are desirable for many collateral purposes. The greatest difficulty in aerial photography I have experienced is to get photographs without tilt; the camera bubble is not a dependable indication and the only reliable test is laborious comparisons and computations from the ground control. Unless tilted pictures are detected and corrected, the portions of the map corresponding thereto will be in error. On the other hand, tilted pictures do not affect the accuracy or speed of automatic plotting. My experience indicates that aerial photographic problems with automatic plotting methods are slightly simpler than with Lieutenant Salt's method.

(3) *Less ground control is required, and no hard and fast layout is necessary. Whatever control there is may be used to the best advantage.*

It is extremely difficult to draw fair comparisons between relative costs of the ground control required with different methods because again so much depends upon the scale and accuracy of the final maps.

For example, if the "aerocartograph" plotting stereoscope were selected for the production of a map of civilised territory to a scale of 1:50,000, we would ordinarily require two control points for each 2.65

square miles. That is at the rate of .75 control points per square mile or 75 points for an area of 100 square miles.

The accuracy of the control is a function of the accuracy required in the map. The control points must be three times as accurate as the map. That is if a tolerance of nine feet is allowed in the elevations as represented by the contours of the finished map, the control points must be determined within three feet of their true elevation.

According to Lieutenant Salt's lecture, four points per square mile are required in his method, which means 400 points for a 100 square mile area. This is five times as much control as required with the plotting machine for a 1:50,000 map, but the comparison may not be entirely fair because Lieutenant Salt may intend to control a different scale of map. However, I am surprised that he can get along with so few points even for the smallest scales. It would be interesting to know how accurate control must be for his method.

In this connection, one very interesting point is the fact that most plotting machines will absolutely not accept a control point which is in error, either in elevation or plan, and startling errors are regularly detected in the most carefully checked ground work. Such errors might pass unnoticed by Lieutenant Salt's method.

(4) *The work of plotting may be sub-divided among a large number of draughtsmen, thereby increasing the speed of map production.*

I believe plotting by machine is more accurate and uniform. It tends to eliminate the human error and quality is only slightly affected by the relative skill of the machine operators. Operators vary greatly as to speed, but only slightly as to quality. I have often had two operators draw a contour on transparent paper and, when superimposed, only one contour could be seen. On the other hand, the skill of draughtsmen often shows in the quality of their work as well as speed.

The speed of production will depend on the number of units working, whether they be teams of draughtsmen or "machines and operators."

6. *The Air Photographic Problem*

With the exception of tilted photographs and the necessity of multi-motored airplanes, my experience checks Lieutenant Salt's conclusions.

I believe it is extremely difficult, if not impossible, to secure any appreciable number of aerial photographs without a small percentage having tilt well in excess of two degrees. It is true that the majority may be satisfactory, but the few bad ones may be as dangerous as the weak links in a chain.

Multi-engine airplanes are desirable in bad country, but also expensive. Photographic flying is the safest of all aircraft operations. Flights are undertaken only when the weather is perfect. The altitudes are high and the tendency is toward greater heights. Therefore, in case of forced landings the pilot has a large area to pick from and good visibility. As a result, for photography single-engine ships are satisfactory over much worse territory than for transport services. The pilot assigned to a large air survey over a portion of the Andes Mountains, a rough, inaccessible, sparsely inhabited region, recently advised me he felt quite confident in his single-engine ship, because at his altitude, even in such country, he usually had an emergency field within gliding range.

Many photographic pilots like a glass bottom in the fuselage of the ship directly under the control stick, in order that they may have clear vision directly beneath them.

7. *Air Survey Procedure*

It is hazardous to prophesy further developments in the art of air survey, but the trends are surely towards multi-lens cameras. The economies which might be made possible through the application of the multi-lens principle were recognised by Scheimpflug thirty years ago, at which time he worked out a design for a nine-lens camera. Something over six years ago, Mr. Leon T. Eliel, of the Fairchild Aerial Surveys, Inc., designed and patented a nine-lens camera which in air tests gives promise of being a splendid instrument. Photogrammetry, G.m.b.H., of München, Germany, has designed a nine-lens camera unit which resembles Mr. Eliel's camera very closely. The economic application of the nine-lens unit is subject to much controversy and the ultimate success is problematical.

U.S. Army three-lens, four-lens and five-lens cameras have all been proved satisfactory under regular service use. The latest of these is the five-lens, which has proved to be so efficient that it is somewhat doubtful if efforts will be made to increase the number of lenses in the near future.

Zeiss-Aerotopograph, G.m.b.H. (a company affiliated with Carl Zeiss, Jena, Germany), has adopted four lenses for its multi-lens camera unit.

Rather than cameras having a greater number of lenses, I wonder if the next big step towards more efficient mapping will not be in connection with high altitude airplanes. Possibly ceilings of 30,000 feet can be reached for photographic work. These higher altitudes would permit much greater areas to be covered on each photographic flight and achieve most of the economies which camera designers are now striving for with their multi-lens developments.

Yours very truly,
Fairchild Aerial Surveys, Inc.,
E. R. Polley, *Vice-President.*

Reply by Lieut. J. S. A. Salt

It is very gratifying to have the opinion of an expert that my paper fulfilled in some small measure its object of presenting in a compact form some cardinal aspects of air survey. The points of disagreement are, I think, due partly to the inevitable omissions of such compression, and partly to the necessity in such a broad subject, of limiting the boundaries of one's objective. The objective in this case was survey from the point of view of developing the British Empire, the immediate crying need of which is for good maps on medium topographic scales, say from 1 : 50,000 to 1 : 500,000. The method described has been arrived at as a result of examining all the factors involved; photographic, topographic and cartographic, from the point of view of technique and personnel, modified by the existing organisation of the Empire itself. It makes no claim to be necessarily the most suitable for a private company operating by contract—the factors involved are usually very different.

These considerations will explain the regretted omission of a discussion of the merits and applications of such plotting machines as those of Wild, Hugershoff, Zeiss, Nistri, Poivilliers, Gallus, etc., all of which have done excellent work, but almost entirely on the larger scales from 1 : 1,000 to 1 : 20,000. With regard to the design of the Fourcade stereogoniometer my somewhat laconic statement was based on the following facts:—

(1) Most of the continental plotting machines, and in particular those of Wild, Hugershoff and Zeiss, were designed originally for terrestrial photogrammetry, where each goniometer in the plotter can be set to a known orientation, and their equivalent separation to a known scale.

(2) In air photogrammetry these latter quantities are not known. They were originally determined by the resection in space of each photograph from four

known points, and the design of plotting machines (*e.g.*, the function of the *x*, *y* and *z* axes) was flavoured with this outlook.

(3) The principles of mutual orientation of two photographs by means of correspondence in five basal planes were expounded first by Dr. Fourcade in 1925 and his stereogoniometer was constructed to carry out this operation in the most efficient manner. The straight line joining the rear nodal points of the goniometer lenses consequently became the air base and the five setting movements were related to this.

(4) Users of other plotting machines also discovered the necessity of the *method*, but the machines they used were not constructed to carry out those *principles*. Consequently various additional movements were incorporated without consideration of the fundamental principles involved.

(5) A result of this is that in such machines the setting for scale and orientation of the relief model cannot be carried out without upsetting the mutual orientation, and the two processes can only be finally achieved by successive approximation or by the use of correction tables or nomograms. In the case of the Zeiss stereoplanigraph, it has led to a curious anomaly. One corner of the famous " Zeiss parallelogram " is moved during setting out of the plane containing the other three, thereby destroying the function of the properties of the parallelogram on which the mechanism is based.

As a result of this neglect of fundamental principles certain of these machines thus introduce definite errors, which, however, under normal conditions are reasonably small. I do not suggest that they do not offer highly efficient and practical solutions to many survey problems, but, to qualify my original statement, I do believe that these faults would be avoided if the designers tackled the problem afresh and from the point of view of air photography first, and that the result would be a plotting machine far simpler in design and of even greater application.

The question of ground control is somewhat thorny, and all generalisations are dangerous. Comparisons can seldom be fairly made unless a particular problem is chosen and all the various factors discussed. In this case, however, Mr. Polley has, I think, slightly misunderstood my statements. Using the method described, the ground control required for a map on a scale of 1 : 25,000, in quality equal to that obtained by good ground methods, is as follows:—

(i) For planimetry: A second order triangulation, say one point per 10-15 square miles.

(ii) For contouring: Four spot heights per square mile. The *positions* of these need not be fixed, and they are obtained by means of aneroid barometers and marking on the photographs.

The particular point urged was the flexibility of the demands on control. In a particular case, for instance, maps on a scale of 1 : 50,000 were produced of an area of nearly 2,000 square miles in Transjordan, where the control consisted of half a dozen astronomical points and a couple of barometer traverses. The results are, of course, by no means perfect, but bearing in mind the nature of the country and the purpose of the map, fulfil the original object in a practical manner.

The question of multi-lens cameras is of great importance for the future. The factors here seem to me to be as follows:—

(i) If the greater angular field available is to be used to reduce the costs of flying, while maintaining a favourable ratio of air base to height, then the area of ground covered at each exposure should, for efficiency, be roughly square in shape.

(ii) If we take an angular field of about 120° across the flats of this square picture as representing the maximum obliquity which can conveniently be used, then in order to make use of the wide angle properties of the modern survey lens, a seven-lens camera is the most efficient.

The American five-lens camera which produces a photograph in the shape of a Maltese cross appears to be of no more value than a three-lens camera. It may be though that I have not the latest information on this point.

I feel sure that Mr. Polley's remarks and my own actually fit without discord into the same framework, and that such differences of opinion as have emerged arise from the widely different points of view from which we approach the problem. A third opinion might be focussed on yet another facet of the central theme. The most important fact, however, is that the great body of data on this subject has now reached a stage where it can offer a suitable technique for the solution of almost any survey problem. It remains to educate the administrator.

REVIEW

Thermodynamics Applied to Heat Engines

By E. H. Lewitt, B.Sc., A.M.I.Mech.E. Sir Isaac Pitman and Sons, Ltd. 12s. 6d. net.

This text book has been written to cover the syllabuses of the B.Sc.(Eng.) and A.M.I.Mech.E. examinations on this subject. It deals with the laws of gases, unicycles, entropy, air compressors, refrigerators and fuels. In addition, seven chapters are devoted to steam engines and turbines, and two only to the internal combustion engine. Considering the extensive modern use of the internal combustion engine as a prime mover in all industrial applications, it would seem that more space might have been devoted to the latter, but it is presumed that this is due to the syllabuses referred to.

The book is clearly written, adequately supplied with diagrams, and can be thoroughly recommended as an excellent text book on the subjects with which it deals.

The 558th Lecture delivered before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS

SECOND MEETING, SECOND HALF, 68TH SESSION

The Second Meeting of the Second Half of the 68th Session of the Royal Aeronautical Society was held at the Royal Society of Arts, John Street, Adelphi, London, on January 26th, 1933. In the Chair Mr. H. E. Wimperis, Vice-President, Director of Scientific Research, Air Ministry.

The CHAIRMAN: The author of the lecture that evening was Wing-Commander G. S. Marshall. He had taken over some of the duties of the late Group-Capt. Flack, who, up to the time of his much regretted death, had been in charge, under the Director of Medical Services, of research work in that Directorate. It was difficult to imagine any more interesting task that any man could have in such a new field or one that had such possibilities for investigation than that with which Wing-Commander Marshall had been entrusted. He had great pleasure in calling upon him to give his lecture on " The Physiological Limitations of Flying."

THE PHYSIOLOGICAL LIMITATIONS OF FLYING

BY

WING-COMMANDER G. S. MARSHALL,

O.B.E., M.R.C.S., L.R.C.P., D.P.H., L.D.S.

It has frequently been remarked as a matter of common knowledge that, from the standpoint of efficiency in its true sense—the relation of output to input—the human body compares favourably with mechanical devices, while it has additional advantages in versatility and adaptability. For example, the human eye can see with great clarity and quickness in a dim light and yet is able to adapt itself to a degree of illumination one hundred thousand times as bright. For another example, think of the extremely complicated co-ordinated movements of walking, talking and writing—things that we habitually do with great accuracy and quite unconcernedly.

But the human body, like all living things, is designed to function within certain limits of environment, and the inevitable result of adaptation to that environment is that when these limits are surpassed the body no longer functions at its best, or indeed does not function at all. The developments of applied science during the last few decades have made it mechanically possible for man to go far beyond his natural limits in many respects, and I propose to discuss those limits and the manner in which they may be artificially enlarged so as to enable man to make the best use of his mechanical aptitude.

The first environmental factor to be considered is that of height, and I use the word " height " in preference to " altitude " for two reasons—first, that where a word of native origin is as inclusively and as exclusively descriptive as its Latin analogue it is usually preferable; and secondly, to avoid confusion with the special astronomical significance of " altitude." I believe that it is correct to say that the greatest height at which man is normally to be found is less than 18,000 feet above sea level. At this height the climate is cold, but not necessarily very cold, throughout the year, and the barometric pressure little more than half what it is at sea level.

Now the air that we breathe is almost uniform in composition in all parts of the world and at all accessible heights, so far as the gases that affect respira-

tion are concerned, containing 20.93 per cent. of oxygen and 0.03 or 0.04 per cent. of carbon dioxide. Dalton's laws of partial pressures state that in a mixture of gases each portion of the mixture contains the gases in the same proportion, and that the pressure of the mixture is equal to the sum of the pressures of the component gases. Further, the respective pressures of the component gases are directly proportionate to their percentages in the mixture. When, however, there is also present the vapour of a liquid or a solid, the case is altered. Dalton's laws state that the pressure and consequently the quantity of vapour which saturates a given space are the same for the same temperature, whether there is or is not any other gaseous substance in the space, and that the pressure of the mixture of a gas and a vapour is equal to the sum of the pressures which each would exert if it occupied the same space alone.

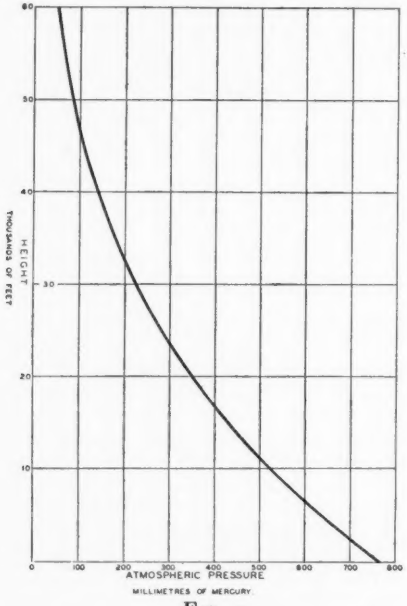


FIG. 1.

Relation between height and atmospheric pressure (I.C.A.N. conventional law).

When air is inspired into the lungs it is assumed to be almost immediately saturated with water-vapour at a constant temperature of about 37°C., the temperature of the body, and this temperature is not materially affected by that of the air inspired, which is warmed or cooled to that of the body by passing over a very large area of internal body surface. The pressure of aqueous vapour at a temperature of 37°C. is about 47 mm. of mercury, and it will be remembered that this pressure is independent of the pressure of other gases present. Consequently, in order to obtain an estimate of the pressure of oxygen available in inspired air, we must take the pressure of the air inspired, deduct 47 mm. from it, and take 20.93 per cent. of the remainder.

Fig. 1 shows a graph that is no doubt familiar to most of you; the ordinates represent height and are calibrated in thousands of feet, and the abscissæ the corresponding atmospheric pressures in millimetres of mercury. This graph has been calculated from the I.C.A.N. formula for what are known as London laboratory conditions.

Fig. 2 shows a similar graph, but this time of pressures of oxygen available in inspired air at stated heights, saturated with water-vapour at 37°C.

The function of the blood in respiration is to take up oxygen and discard carbon dioxide in the lungs, and to reverse this process in the tissues and organs, so that it acts as a carrier of oxygen from lungs to tissues and of carbon dioxide from tissues to lungs. The part of this function that relates to oxygen is done by the medium of the substance that gives blood its colour—hæmoglobin—which has the property of forming exceedingly rapidly a loose affinity with oxygen and of giving it up to the tissues as required. Unfortunately, its affinity for the deadly gas carbon monoxide is about 300 times as great as for oxygen, so that extremely small percentages of carbon monoxide are lethal by supplanting the vitally necessary oxygen.

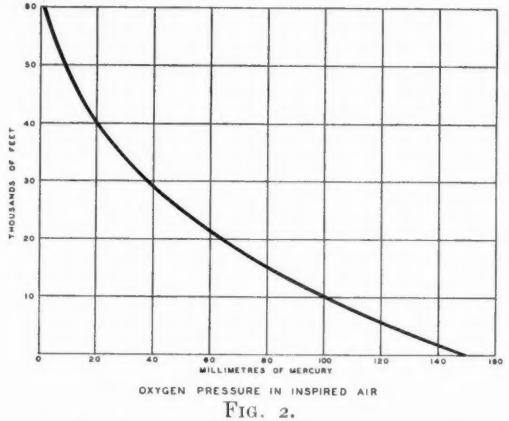


FIG. 2.

Relation between height and partial pressure of oxygen in air saturated with water-vapour at the temperature of the human body (37 C.).

The amount of oxygen taken up by the hæmoglobin of the blood is a function of the pressure of the oxygen to which it is exposed, and reaches saturation point when that pressure is about 150 mm., which is the pressure of oxygen in air at ground level (762 mm.) saturated with water-vapour at 37°C. The graph in Fig. 3 shows the percentages of full saturation of oxygen in blood corresponding with the stated pressures of oxygen.[1]

Man can exist very well with far lower degrees of saturation with oxygen in blood than 100 per cent., and the degree of saturation necessary depends to some extent on the amount of work he is called on to perform, being naturally higher with heavy work than at rest. It is impossible to give any exact estimate of this, as individuals both differ and vary, but as a general rule the oxygen pressure in wet inspirate (*i.e.*, in inspired air saturated with water-vapour at body temperature) under conditions of not more than moderate exercise may be reduced to about 80 mm. without untoward effect. This is confirmed by the fact that when the alveolar air is analysed (*i.e.*, the air inside the ultimate recesses of the lungs, which contains also carbon dioxide at a pressure round about 30 mm.) it is found that 50 mm. of oxygen pressure represents the turning point between comfort and distress. Below this figure distress increases with great rapidity, and it may be stated that oxygen pressures in alveolar air of above 50 mm. represent respiratory comfort; in the forties some degree of distress; in the thirties, severe distress; and below 30 mm. the subject is likely to faint.

If we now compare these figures with the oxygen pressures actually available in wet inspirate at various heights, as shown in Fig. 2, we see that the

turning point of 80 mm. of oxygen in wet inspirate corresponds with a height of 15,000 feet, and the rather arbitrary fainting point of something below 60 mm. of oxygen with a height of about 22,000 feet, which is in close agreement with the findings of practical experience. Note here that I do not say that a man will faint without additional oxygen at 22,000 feet; I say that if he goes rapidly to that height he is in danger of fainting. The use of the word " rapidly " here calls for explanation. When the human body meets an unaccustomed environment it generally makes some effort to adapt itself thereto, and so it is in the case of the rarefied atmosphere encountered at great height. But this adaptation, which consists of the manufacture of a greater number of red blood corpuscles than normal, each with its charge of hæmoglobin, takes considerable time, running into weeks, so that expeditions to climb very high mountains

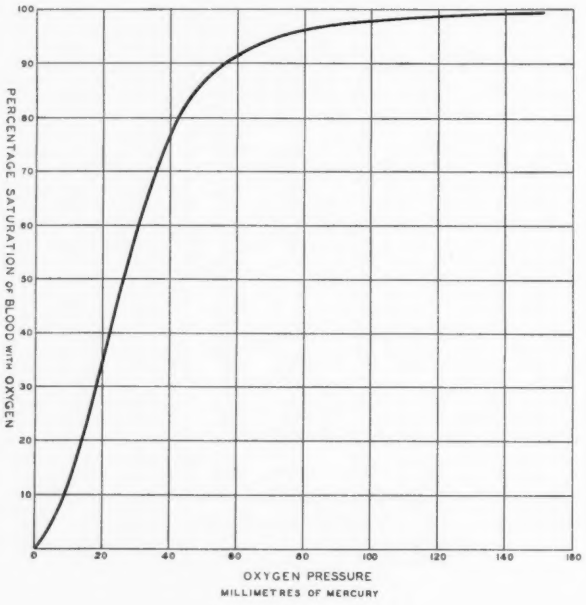


FIG. 3.

Relation between oxygen-pressure and degree of saturation of hæmoglobin with oxygen resulting therefrom.

become to some extent acclimatised to height by periods of a week or more spent in camps at progressively increasing heights. There are normally 5 to 5½ million of these minute bodies, each containing about 32 per cent of hæmoglobin, in each cubic millimetre of blood. This number may increase, on acclimatisation to height, to 6 million at 8,000 feet, 6.8 million at 12,000 feet, 7.9 million at 16,000 feet and 8.3 million at a little over 18,000 feet.

For the reasons stated, it is desirable that pilots and passengers in aircraft should not ascend above 15,000 feet without oxygen if they are going to remain at that height for any length of time or do more than light physical work, nor should they ascend above 18,000 feet without oxygen for ceiling tests where they do virtually no physical work. If they disregard this injunction, they are liable to suffer from the effects of oxygen want, and as no pilot can be quite

certain while flying that the necessity of carrying out some physically strenuous manœuvre during the next few minutes cannot possibly arise they should bear in mind that the sudden respiratory tax might cause them to faint with possible results better left to the imagination.

The obvious way out of this difficulty is to increase the partial pressure of oxygen in the inspired air. There are many ways of doing this, and for aeronautical purposes the simplest practicable way is by allowing a regulated stream of pure oxygen to enter a mask fitted over mouth and nose, the mask having apertures through which air can be breathed. This method is in general use throughout the world, but has certain disadvantages.

First, it is wasteful. Of the whole cycle of respiration about one-third consists of inspiration, the remainder being accounted for by expiration and the neutral phase which follows it. If, therefore, oxygen is being poured out into a small mask continuously it is being breathed-in for only about one-third of the total time of use, the remaining two-thirds being wasted.

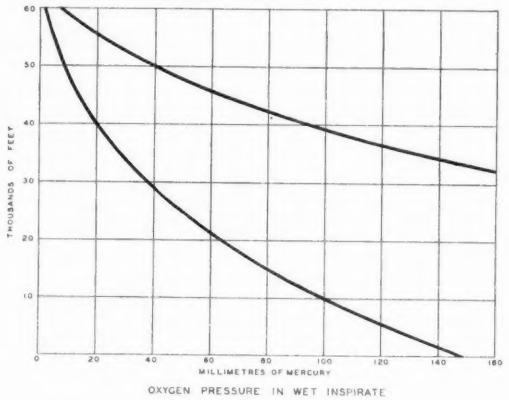


FIG. 4.

Relation between height and partial pressure of oxygen inspired into the lungs when breathing (below) air, and (above) oxygen.

Secondly, it is based on the assumption that what is needed is an additional *amount* of oxygen, the true requirement being additional *pressure* of oxygen in the inspired air. These two are, indeed, related, but they are not synonymous. The result of this is that when the subject is called on to exert physical effort, and in consequence breathes more rapidly and deeply, more air is drawn in through the holes in the mask, where it is mixed with the same flow of oxygen as sufficed for quieter breathing. The resulting air-oxygen mixture is therefore weaker in oxygen than before, and since one result of deprivation of oxygen is a compensatory increase in respiration, a vicious circle is immediately established. This may be overcome by increasing the rate of flow of the oxygen, which, however, is but a clumsy makeshift, since it increases the already high rate of wastage and is in practice quite unreliable.

So long as oxygen is cheap, the weight of unnecessarily large cylinders immaterial, and neither height nor muscular effort immoderate, this method of oxygen addition is good enough. In order that you may see where the height factor begins to be really important, I have prepared (Fig. 4) a graph showing (below) the same curve that you have already seen, illustrating the relation between height and the oxygen pressure in wet inspired air, and (above)

the relation between height and the oxygen pressure in wet inspirate when breathing pure oxygen to the absolute exclusion of the atmospheric air. Here I would remind you that the idea of breathing pure oxygen is a theoretical fiction, partly on account of the impracticability of supplying 100 per cent. oxygen and absolutely excluding the atmosphere, and partly because of the additional dead space of any mask, however small, in front of nose and mouth, which must necessarily serve to dilute the incoming oxygen with expired gases to a greater extent than normal.

From this graph you will see that a person breathing pure oxygen at a height of 42,000 feet is under the same respiratory conditions as if he were breathing air at 15,000 feet, while breathing pure oxygen at 50,000 feet is directly comparable with breathing air at 29,000 feet. For these theoretical reasons I am of the opinion that the safe limit of height for a person breathing pure oxygen is 42,000 feet if he is to take moderate exercise, and 44,000 feet if he is merely to go up and come down again immediately. Again I would emphasise that these figures represent what I regard as the limit of safety and not the limit of possible performance.

How, then, are flights at heights greater than these to be undertaken with safety? The answer is, by maintaining the atmosphere to which the pilot is exposed at a pressure within the indicated limits. This can be done by causing him to breathe air while the cockpit pressure is kept up to 430 mm., corresponding to 15,000 feet, or to breathe pure oxygen in a cockpit pressure kept up to 130 mm., the equivalent of 42,000 feet. In this connection it is important to keep the difference between internal and external cockpit pressures as low as possible, not only because of the risk of structural collapse if the difference is large, but also on account of the biophysical effect of sudden deep falls of atmospheric pressure. If the sealed cockpit were to burst with a high difference of external and internal pressure, the strain of the sudden relative internal pressure on the ear-drums would be very painful and might be enough to split them, though this is hardly likely in view of the fact that the Eustachian tube, which connects the otherwise closed middle ear with the back of the nasal cavity, is something like a valve, permitting air to pass more readily from the middle ear than to it. There is also to be considered the possibility of a sudden extensive fall in atmospheric pressure causing damage to the body by the liberation of blood gases in the form of minute bubbles. When soda water is drawn off from a siphon, it is seen that the liquid remaining continues for some time to give off small bubbles of gas on account of the reduction of pressure above it, and when blood that has been exposed to the atmosphere is subjected to a reduction of pressure under the bell jar of an air pump the same thing occurs. When divers descend under water to a considerable depth, they are supplied with air for breathing at a pressure rather greater than that of the water above them, and their blood therefore becomes saturated with air at that increased pressure. This process of saturation gives rise to no untoward symptoms, but when they wish to ascend they must do so only very slowly, in order to allow the gas that has been forced into the blood to escape again by the lungs. If they ascend faster than this, the blood gases, unable to escape fast enough through the lungs, behave like the carbon dioxide in the soda water siphon and come off in bubbles which may obstruct the tiny terminal arteries, while the same process occurs in the spinal cord, etc., causing severe cramps, paralysis, vomiting and other distressing symptoms.

But in considering how far this " caisson disease," as it is called, is likely to affect pilots exposed to a large drop in atmospheric pressure through the sudden rupture of an adiabatic cockpit, we must remember that while in rising from a depth of water of only 34 feet the atmospheric pressure is reduced by one atmosphere, the entire range of pressure in rising from the ground to many times the greatest height attainable is less than one atmosphere, so that I think

that the pressure drop from the bursting of a cockpit cannot possibly cause this sort of trouble.

It would no doubt be mechanically possible, instead of seating the pilot in a sealed cockpit at a relatively high pressure, to enclose his whole body in an impermeable suit, or his head and neck in a sort of diver's helmet. The helmet has the virtue of not requiring a special type of cockpit, but it has many disadvantages. It would be most unwieldy, it would inevitably interfere with the pilot's free movement to an undesirable degree, it would increase the respiratory problem of dead space, it would subject the pilot to different pressures inside and outside his thorax, so that resistance to inspiration would be reduced, and to expiration increased, and it would be very difficult to devise a fastening for it about the chest and shoulders which would be both airtight and readily detachable without excessive weight.

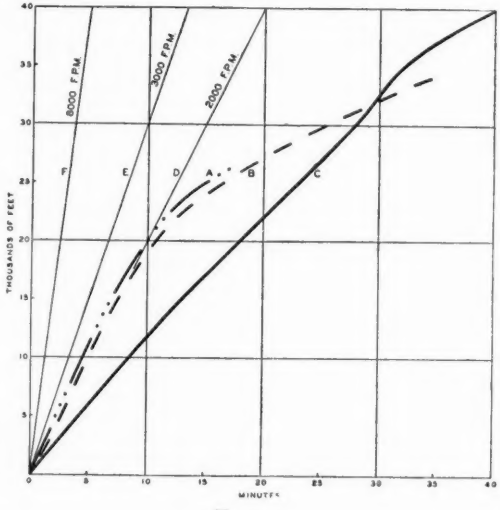


FIG. 5.

Rates of Ascent.

The next problems to be considered are those of rate of ascent and rate of descent, and I have already mentioned these in dealing with pure height. So far as the rate of ascent is concerned, I think that mechanical performance will have to be enormously improved before there is any need to consider biophysical limitations. Fig. 5 shows rates of climb of three types of aircraft. A is a modern high-speed Service aeroplane, B the French Morane "Jockey" (500 h.p.),[2] and C the Vespa-Pegasus[3] in which Flight Lieutenant C. F. Uwins made his successful attack on the world's record for height. Curves D and E represent the rates of climb habitually and occasionally used in the decompression chamber, and there is no reason to believe that curve F, which represents a rate of climb of 8,000 feet a minute, would unduly tax a pilot in good health.

As for the rate of descent, the case is rather different. The process is one of compression, and the solution of gases in the blood presents no difficulty. But the valve-like Eustachian tube tends in descent to close against the minute quantity of air seeking to enter it and restore equilibrium of pressure on the two sides of the ear-drum, so that it is more necessary in descent than in ascent to practise whatever manœuvre the pilot is accustomed to use for this purpose—

swallowing, blowing against closed nostrils, or thrusting the jaw forward. And in both ascent and descent it should be borne in mind that a quite trivial cold in the head is apt to cause the mucous membrane or skin lining the Eustachian tube to swell and so obstruct the tube, partially or even completely. This is one of the reasons why pilots should not fly when suffering from a " cold." It is difficult to say more about the limiting rate of descent, since the evidence is conflicting. On the one hand are statements by experienced pilots that rates of fall in excess of 2,000 feet a minute are apt to cause discomfort, and on the other the fact that power dives are done at the almost unbelievable speed of 30,000 feet a minute without apparent harmful biophysical effect. It is quite certain that long high-speed dives in a state of unconsciousness may result in rupture of the ear-drum, and so if a pilot wishes to dive from a great height with a passenger he should take a glance at him before doing so in case the passenger's oxygen supply may have failed, and in this connection the pilot should remember that the oxygen flow that is adequate for him might with some types of apparatus be inadequate for an observer strenuously operating a camera, gun, or other device.

The next limitation is that of speed, and here I beg leave to digress for a moment. It is only during the last century that the maximum speed of travel has advanced from what it had been for some thousands of years—the speed of the racehorse. By travel I mean, of course, voluntary travel without harmful effect. It is true that men have actually travelled faster than this, as for example in high dives or falls, or when the Romans under the Empire, who had no prisons, found the continued existence of some poor wretch undesirable and hurled him from the Tarpeian Rock, or when the catapults of the Middle Ages were used to return an unpopular envoy to his master. The speed of the racehorse represents the limit of speed for an animal of quadruped structure, and even man can put up a speed of 30 miles an hour for the last 15 yards of a hundred-yard sprint. There may have been some form of ice or snow travel faster than a racehorse 100 years ago, though it cannot have been extensively used as a means of travel. A little more than 100 years ago the Liverpool and Manchester Railway was opened, after infinite labours to get the necessary measure through Parliament. A few of the remarks made about that time will serve to show the attitude of the bulk of mankind towards speed in general. The *Quarterly* said of a proposed railway to Woolwich: " What can be more palpably absurd and ridiculous than the prospect held out of locomotives travelling *twice as fast* as stage-coaches? We would as soon expect the people of Woolwich to suffer themselves to be fired off upon one of Mr. Congreve's ricochet rockets as trust themselves to the mercy of such a machine going at such a rate. . . . We trust that Parliament will, in all railways it may sanction, limit the speed to 8 or 9 miles an hour, which . . . is as great as can be ventured on with safety." Nicholas Wood, an engineer and a friend who often assisted George Stephenson, said: " It is far from my wish to promulgate to the world that the ridiculous expectations, or rather professions, of the enthusiastic speculist will be realised, and that we shall see engines travelling at the rate of 12, 16, 18 or 20 miles an hour. Nothing could do more harm towards their general adoption and improvement than the promulgation of such nonsense." A few months later, at the opening ceremony of the Liverpool and Manchester Railway, Mr. Huskisson, one of the Members of Parliament for Liverpool, was run over by the " Rocket." Badly hurt, he was carried by George Stephenson on the " Northumbrian " a distance of 15 miles in 25 minutes, or at 36 miles an hour.

Since then, the world has seen the speed record slowly climb to about 80 miles an hour towards the end of the 19th century, since when the development of the internal combustion engine in the last few decades has made the record shoot up to over 250 miles an hour on land and 400 in the air, and these

are not the highest speeds ever reached, but are average speeds for a series of trials under standard conditions.

Moved more by superstitious dread than knowledge, people have said that there must be a reckoning for such breaches of the natural law, that there must be a limit to the speed at which man can travel with some measure of safety, and that we have already reached that limit. As regards pure speed, a moment's reflection will show the absurdity of this. Speed is relative; our whole country is being whirled about the axis of the earth at about 600 miles an hour, the earth carries us around the sun at something like 60,000 miles an hour, and so *ad infinitum*. Pure speed can be dealt with summarily by the statement that there is no physiological limit to the speed at which man may travel uniformly and in a straight line. As soon, however, as substantial alterations of speed are introduced they involve the question of acceleration or its converse, while departure from the straight line involves the allied problem of centrifugal force.

So far as straight flying is concerned, I do not think that acceleration or deceleration presents any problem yet. Everyone knows how the enormous and destructive deceleration encountered when a man jumps from a high window to the ground is usually reduced to harmlessness by the use of a jumping-sheet, which operates only during the last yard of his fall. Provided that the thrust of acceleration or deceleration is more or less evenly distributed over the whole of his body, and that neither head nor limb is allowed to be jerked backwards or forwards by inertia, the pilot has little to fear from these forces, unless they are increased out of all comparison with their present customary values.

But when it is a question of rapid angular deviation at high speed it has to be confessed that we have already passed the limit of safety. The most commonly encountered example is in a properly banked but very sharp turn at great speed or in coming out of a very fast and steep dive. In such a manœuvre the pilot tends to be thrust down into his seat by centrifugal force, which may amount to many times his own weight. Here I use the word "down" gravitationally, in reference to the pilot and his seat, and without regard to the direction of the earth. It is, of course, not only the pilot as a complete entity that is thus forced down; every part of the aircraft bears down with enormous force against the air resistance encountered by the wings and elevator, and similarly the weight of every constituent part of the pilot's body is multiplied. So far as most of the structures of the body are concerned this thrust is no more than can be borne by the bony and ligamentous semi-rigid framework on which it is constructed, but the liquid contents of the body have no such purchase. The effect most frequently noticed is the well-known phenomenon of "blacking-out," wherein the subject without losing consciousness becomes momentarily blind. In discussing the cause of this it is only right to say that we are not all agreed. Some say that the immediate cause is a driving away of blood from the eye, others say that it is due to local loss of blood in the brain, and there are other theories not yet published to which I am therefore unable to refer. I believe that such evidence as there is points to an immediate effect on the eye itself, probably on the blood supply to the retina, the light-sensitive recording surface. If this be the case, it accounts for the converse phenomenon of "redding-out" which has been observed in an inverted loop, where the centrifugal force acts in the opposite direction. If blacking-out were caused by an anæmia of (or removal of blood from) the brain, then it seems most likely that the converse would be not a diffuse red glow but flashes of subjective light, not necessarily constant in colour—just as the brain effect of a blow on the point of the jaw is to make one see "stars." But the outside looper does not see stars, he sees merely a dim suffusion of red into his visual field, and I am now going to suggest that this is a pressure effect and is identical with the "seeing red" of the exasperated hero of fiction, or with the reddish spots sometimes seen by

the very vigorous candidate at the Central Medical Board when asked to demonstrate how far he can blow mercury up a vertical tube.

Given the hydraulic nature of blacking-out, the next question is whether there is any necessity to do anything to counteract it, and if so, what. So far as the terrific hairpin turns of the Schneider course are concerned, I understand that it is not necessary, since it is generally agreed that the same centrifugal force that blinds the pilot also slows down the aircraft so that the very tight turn is actually less profitable than a wider rising turn in which the blacking-out effect is negligible. It might be well here to mention the degree of force encountered. Blacking-out is commonly found after about one second at a force of $3\frac{1}{2}$ to $4\frac{1}{2}$ G. Forces of 6 and 7 G. have been recorded in this country without mishap, and the highest recorded force of this nature is, I believe, one of 11 G. in America, which was unfortunately not without mishap. (This figure is unsupported hearsay.) Redding-out has been recorded after a much lower negative acceleration of about 2 G.

If it is agreed that these rates of acceleration are to be expected in aircraft—and this is of course not a physiological question—the biophysical problem of prevention arises. It may be mentioned in passing that there is no question of treatment as the time factor alone rules this out.

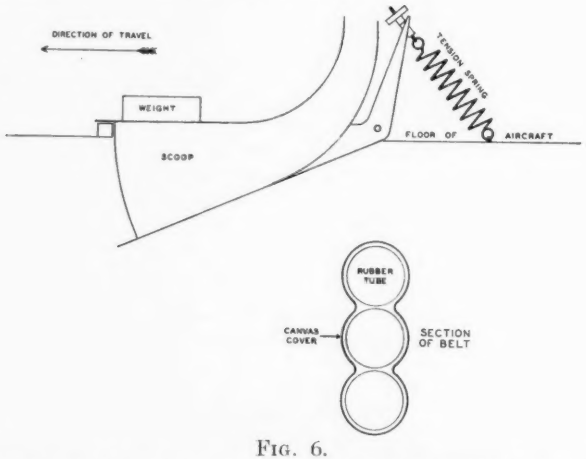


FIG. 6.

Suggestion for a pilot's belt to neutralise the effect of extreme centrifugal force.

Blacking-out, then, I believe to be due to anæmia of the eye from the pooling of blood in the relatively unsupported, and gravitationally lower, abdominal vessels. I believe that if the causative force were allowed to continue in operation for an appreciable length of time (say, 10 seconds) it would cause fainting, and that a good deal can be done to prevent these effects by momentary bracing of the entire abdomen by means of either careful training and use of the natural muscles or the use of an artificial aid in the form of a broad, flexible, but inextensible belt or corset.

Because the attention of the pilot in such circumstances as those of a high-speed tight turn is fully occupied with other matters, I regard it as essential that any such artificial aid should function entirely automatically in all respects, and Fig. 6 shows a sketch of a device which I suggest might serve to counteract the tendency of centrifugal force to make the blood leave the head and pool in the thin-walled abdominal vessels.

You will see that it consists of a scoop and a sort of specialised safety belt or corset. The scoop is fitted to the aircraft in such a manner that a weight tends to force it out, hingeing about the transverse axis of its throat, into the slipstream, while a spring, operating in the opposite direction, normally overbalances the weight and keeps the scoop closed into the fuselage so as to offer no air resistance. The throat of the scoop is connected by means of a short flexible inextensible wide-bore tube to the corset, which consists of two wide bands of something like canvas, joined at their edges and embracing an impermeable lining. These bands are horizontally quilted so as to distribute their pressure, when inflated, evenly over the whole abdomen, thus dividing the structure of the corset into, say, three or four pneumatic tyre-like rings of equal size.

The *modus operandi* is, I think, quite obvious. When centrifugal force, operating on the aircraft, reaches a predetermined figure, the weight of the scoop overcomes the tension of the spring and driving the scoop out into the slipstream suddenly inflates the pilot's corset to its maximum, which has been previously adjusted to suit his girth. This pressure is maintained so long as the centrifugal force is enough to keep the spring-loaded scoop out in the slipstream and as soon as the force slackens the scoop returns in-board and the corset deflates. You will, no doubt, appreciate that this is no more than a sketchy idea, and I shall be glad of any constructive comments.

Other factors that I should have had to discuss, had this been an academic discourse, are endurance, temperature, wind pressure, solar radiation and composition of atmosphere, but I do not think that the occasion calls for any remarks in connection with these.

I have endeavoured to show that the range of environment in which the human can function properly is not unbounded. In some directions the developments of modern mechanics have brought man within sight of his natural boundaries or even into touch with them. In nearly every case it is possible to devise artificial aids whereby these natural boundaries may be greatly enlarged, but until this is done it is well to remember that man exceeds his environmental limits only at his peril.

REFERENCES.

1. The physiology of muscular exercise. Bainbridge.
2. La vitesse d'ascension et de descente en avion. Strohl.
3. Personal communication to the Author.

Discussion

The Chairman: The author had raised many points of immense interest, and although he had no doubt a great many present would wish to speak, one of the few advantages of being the Chairman was that he could get in the "first shot." It had been hoped very much that the distinguished leader of the Mount Everest Expedition, Air Commodore Fellowes, would have been present to take part in the discussion, but apparently he was still occupied with the flying experiments that were being carried out at the Westland Works, which so far seemed to have been very successful.

The physiological limitations of flying, continued the Chairman, could roughly be divided into two quite separate things; one was the effect of the more tenuous air inspired at height, and the other was the effect of aerobatics on the blood. As regards the former, the author had given reasons for arriving at the conclusion that the height limit at the present moment was 44,000ft., and it was to be hoped that during the discussion Capt. Uwins, who in his wonderful flight reached that precise height, would have something to say. He did not know who got "there" first, Capt. Uwins or the author, but there was a very remarkable coincidence in these two figures and it would be extremely interest-

ing if Capt. Uwins would say whether he looked upon 44,000ft. as the safe limit in the manner the author did, or whether he felt himself very much in hand when he reached that height and that had he had time or opportunity to get to a greater height than 44,000ft., he would have been willing to take it on. The author had described the wasteful way in which oxygen supply was often worked. He pointed out that the lungs were only breathing in for one-third of the cycle and that if the oxygen were being supplied all the while it seemed that two-thirds of it must be lost. No doubt the author was well aware of methods which were being considered for overcoming that. The author had, he thought, omitted one thing that might be serious when he discussed the sealed cockpit. It seemed to the Chairman that one limitation of the desirable pressure-difference was the fear of leakage. In any scheme for breathing-in oxygen from bottles the less leakage there was from the sealed cockpit the better; it could not of course be entirely sealed because there were controls passing out of it and they could not all be electrical.

The accelerations referred to by the author were due to aerobatics and it was that condition which decided the load factors to which the machines were built. A number of figures were given in the paper of the kind of "G." encountered both here and in America and the author was very modest as to the accuracy of them. As a matter of fact, however, he himself could say that these figures were really well authenticated, including the one from America. The 11 G. encountered there was met by a pilot who did not want it. He was taken to hospital afterwards, but in a short time, he understood, he was back flying again. Merely to indicate what acceleration of 5 G. meant he would give the following example. If one took a simple garden swing, the sort of thing with iron rods used in a fair and with arrangements for strapping the passenger in, whatever the length of the rods the result of a 180 degree swing from the top would always be 5 G. as read on ordinary maximum accelerometer. The only difference obtained by varying the length of the rods of the swing was a variation of the time factor to obtain that acceleration. It always came out at 5 G. provided the swing went through 180 degrees from the top. Incidentally, the Chairman told a little story about speeds on the road and the manner in which many years ago people were frightened of speed. The incident took place a good many years ago, certainly long before the days of motor cars, when he was bicycling in a street towards Hammersmith and was stopped by a policeman for going too fast. He was told that he was travelling at 8 miles an hour and that that sort of thing was not allowed.

In conclusion, the Chairman said the Aeronautical Research Committee had urged that it would be a very good thing from the research point of view if an aircraft was built to fly at very great heights in order to gain some experience of flying under these conditions. He was sure everybody interested in aeronautics would be of the same opinion as himself in expressing the hope that nothing would occur which would prevent the recommendation of that Committee being fulfilled.

Dr. HAYTHORNTHWAITE: The author had not referred to the effects of oxygen starvation on the higher processes of the brain. These were perhaps psychological, but had their root in physiology. They were certainly less dramatic than loss of consciousness, but essentially no less important and emphasised more frequently and very clearly the necessity for an adiabatic cockpit.

Secondly he said that man had evolved living on this earth in constantly changing temperatures, changing not only daily, but at all seasons and longitudes. He had evolved a temperature-balancing mechanism. But he was completely unable to adapt himself to such wide and sudden pressure changes as were now encountered. He had only evolved to meet the ordinary variations of barometric pressure at the particular height at which he lived.

Therefore one would have imagined that the thinking designer of a modern aircraft would have protected him first against pressure changes, since against these he was impotent, and only in the second place against temperature changes.

What had happened? So far, just the reverse. They had put temperature first instead of pressure, and equipped the aviator with clothing so cumbersome and restricting that the mere wearing of it induced fatigue.

His only comment on the diagram of the scoop was whether it could replace itself when once open, owing to the force of the slip stream tending to hold it open.

Capt. C. F. Uwins: While he had listened to the lecture with very great interest he feared he was not competent to discuss it from the medical aspect. The Chairman, however, had mentioned the question of flying above 40,000ft., and had asked him whether he thought 44,000ft. was a definite limit. As a matter of fact, his own impression, which he came to in consultation with the author after he made his flight of 44,000ft., was that this was not the limit. A flight above 42,000ft., however, ought probably to be limited to 40 or 45 minutes, and he had come to the conclusion that the effects of oxygen starvation over 42,000ft. became cumulative. If one had a machine capable of ascending to 50,000ft. it should be possible to get up to 47,000ft., and down again below 42,000ft. before suffering inconvenience. He had tried several flights since the record and got up to the same height again, which appeared to be the ceiling of the aircraft, and towards the end he began to feel very severe reactions, doubtless owing to the starvation of oxygen which he had referred to. In conclusion, Capt. Uwins said he was extremely glad to have this opportunity of paying a small tribute to the work of Wing-Commander Marshall and the help he had given in carrying out the record flight. Without that assistance and also that of Mr. Taylor at Farnborough, it would not have been possible to have carried out the flight.

Sir Leonard Hill: His excuse for speaking was first of all that the late Group-Capt. Flack began his career as a demonstrator in his laboratory where work was started which was finally developed to such advantage in Air Force tests. So far as the lecture was concerned he had hardly any criticisms to make of it because he was almost in complete agreement with every word that had been said. The point had been mentioned that no man lived permanently above 18,000ft., and in that connection he would like to record that his colleague at the National Institute of Medical Research before he retired—Dr. Argyll Campbell—had carried out a most extensive and accurate and valuable set of researches upon animals, gradually bringing them to keeping them for three weeks or thereabouts at various low pressures. By studying the results on all kinds of animals it was conclusively shown that with these animals the limit for time acclimatisation was 20,000ft. Above that point the animals steadily deteriorated and important tissues such as the heart and the liver underwent increasing degeneration, which was most visible under the microscope when the animals were killed and examined. Nothing would stop that deterioration taking place as long as the animals were submitted to the low oxygen supply which exists above 20,000ft. The power of the oxygen to combine with the hæmoglobin of the blood suddenly diminishes at this level. This was the reason why man did not live above 18,000ft. and when it was claimed, for instance, that the Mount Everest climbers would be truly acclimatised above 20,000ft., the evidence was all against it. The climbers must try and get up quickly and get down again because the longer they stayed above 20,000ft. the more they would deteriorate.

Mention had been made by the author of the pressure of carbonic acid and water vapour in the alveolar air of the lungs, a most important matter. It was

always assumed that water vapour pressure was 47 mm. of mercury, whilst carbonic acid was taken at about 30-40. Some experiments were published in the last number of the Journal of Physiology measuring the actual vapour pressure in the lungs by a new method of great accuracy, and it had been shown by these observers that on rapid and quick breathing the vapour pressure might be lowered to 37 mm. and this was the pressure likely to pertain in the Everest climbers at 28,000ft. It showed the limit of existence. The carbonic acid tension also might be lowered to 22; figures of 22 and 37=59 were much better than those of 47 and 30=77; 1g. more could be allowed for the oxygen tension in the lungs.

In the matter of breathing oxygen, it was most important that it should be as pure as possible. He had recently been carrying out, with the help of Sir Robert Davies at the Siebe Gorman works, some experiments on animals at low atmospheric pressures. The chamber was filled with 98 per cent. oxygen and then pumped out, a watch being kept on the barometric pressure. When barometric pressure had been lowered from 760 down to 100 mm. Hg. it was found that goats were not quite comfortable and began to sit down. If the barometric pressure was increased to 110 mm. they began to stand up again, whilst if the pressure was reduced to 90 the goats were very distinctly distressed, the distress, however, again being immediately abolished on the letting in of more oxygen and raising the pressure. A monkey went to sleep when the pressure was reduced below 120. It quietly closed its eyes and just sat there sleeping, but the moment the pressure was increased it opened its eyes and began to move, again going to sleep when the pressure was reduced below 120. There might be differences, of course, between one monkey and another, just as between one man and another. Given pure oxygen to breathe Capt. Uwins might perhaps be able to go a little higher until the pressure reached say 110 mm. An observer named Talenti had put men breathing oxygen in a chamber down to a pressure of 115 mm. of mercury.

There was no danger of the liberation of blood gas bubbles during a rapid ascent. He had put animals in a small chamber and evacuated a large one and then turned on the cock between the two to see whether it was possible to produce the bubbles which are seen on decompressing animals rapidly from high pressures. He had only seen a few bubbles in one animal out of a great many in spite of such instantaneous decompression, and all of the animals appeared unharmed. There was, however, another thing which might possibly cause trouble. There might be gas in the stomach and intestines and when a person was put in a chamber which was evacuated or went up to a great height, that gas would expand the stomach and press upon the heart and cause discomfort. That and the ear were the only places where change of pressure had any mechanical effect. A change of pressure equally distributed all over the body had no mechanical effect at all upon the circulation. He had spread the web of a frog over the glass window of a chamber and illuminated it with an arc lamp, and to throw a view of the circulation through a microscope on to a screen. The frog had then been exposed to a pressure of 20 atmospheres in a few seconds, but the circulation went on absolutely unchanged. If a chamber was used in an aeroplane to go to very great heights every care would have to be taken not to have unequal pressure at the body of the pilot, because that would be disastrous, owing to the blood being squeezed from the place where there was more pressure into the place where there was less pressure.

The scoop described by the author was extremely ingenious and he quite agreed with all the author had said concerning it, and blacking out. One of the first researches he ever did was with regard to the effect of gravity on circulation and he had shown that animals had naturally great power of keeping up the blood pressure when changed from the horizontal to the vertical position.

Provided the muscles were tightened up the circulation went on all right. If one took a big hutch rabbit with flaccid abdomen, and held it in the vertical position, the blood would sink down and the animal would faint. If a snake were fixed lengthwise in the vertical position and the heart was exposed it would be seen that the blood had sunk down below the heart, but when the animal was put in the normal position the heart filled from the veins and the circulation began again. So, too, when being whirled round by centrifugal force blacking out took place owing to blood leaving the eyes. The effect of this could be got over by tightening up the belt. The idea suggested by the author was well worth trying.

As to the people who were going to fly over Mount Everest it had already been shown that they were being well provided with oxygen. He had tested quite recently some of the men who were going to take the films and up to 35,000ft. in the decompression chamber with the oxygen apparatus in use they were quite normal and of good colour. The Everest climbers were getting only 1½ litres of oxygen a minute; and this was barely enough for hard work. It was all wrong, in his opinion, to proceed on such lines; the oxygen should be used efficiently. What was required was a self-contained apparatus using a CO_2 absorbent and the oxygen economically; such a self-contained apparatus could be made weighing 15lbs. or 16lbs. and lasting about four hours. He strongly maintained that the Everest climbers should have such self-contained apparatus carried up by porters to each of the higher camps and then the selected climbers for the final climb could pick them up and make their final dash to the top and back again as safely as if climbing an Alpine peak.

The CHAIRMAN: He expressed the sincere thanks of the Meeting to Sir Leonard Hill for his interesting remarks, and added that everybody would await with great interest the results of the experiments in the closed chamber. He was not aware whether Sir Leonard expected anybody present to volunteer to go into that compression chamber and assist in the experiments, but if so Sir Leonard's description of what he did to the monkey and rabbit would probably help them to come to a decision!

Wing-Commander ORLEBAR: It was difficult to make any comments, because the matter with which the lecture dealt, though intensely interesting, was too far above his head to allow him to make any really useful remarks.

There were, however, one or two very minor points which he might make concerning the belt described by the author.

First of all, there was the question of whether it would be useful to wear the belt.

So far as work for the Schneider Trophy was concerned they had come to the conclusion that it was unnecessary to apply sufficient G. to cause blacking out even without a belt. They did not prove quite definitely that the average pace would be decreased by a very high G., but they certainly did find that it was not increased by raising the G. beyond anything that the pilot could stand without difficulty. In this connection it appeared that the author put the amount of G. that was troublesome a little low. He understood the author to say that 3 G. had some effect, whereas their pilots did not actually notice anything below 4½.

They had once or twice tried the effect of maintaining a fairly high G for comparatively protracted periods, of course at a safe height. They went up to three or four thousand feet and kept the G. on the machine long enough to do 2 or 2½ complete turns, which would probably mean that the black out lasted at least 20 seconds. In these few trials nobody, so far as he was aware, had any signs of loss of consciousness, and he himself had retained the feel of the controls throughout.

They had carried out turning trials over a fair range of speeds, and had not found that the amount of G. necessary for efficient racing purposes rose

appreciably from two hundred to three hundred and fifty miles an hour. It would therefore appear that the belt was not required for racing, but for aerobatics it might be a different matter and with rising speeds the belt might be very useful for that purpose.

The late Group-Capt. Flack produced a belt in 1929 which was more or less an ordinary elastic belt, and one or two tried it. However, it was rather unpopular because the space in the cockpit was fairly confined in any case and the belt gave the impression of feeling even more cramped. At the same time, some of the pilots found a benefit by tightening up the belly-muscles in doing the turns, as long as they avoided holding their breath. If they stopped ordinary breathing the blacking out came on more quickly.

Flight-Lieut. STAINFORTH: He could not add very much to what Wing-Commander Orlebar had said, although there were one or two points he might allude to. The author had mentioned the question of the difference of acceleration due to turning and due to opening and closing the throttle. Actually there was no trouble with that at all because with aircraft there was very much less acceleration due to suddenly opening or closing the throttle than was obtained on the road. As to blacking out, his own impression—which might be wrong—was that it is not actual blacking out but just a sort of gradual dimming of the sight as if the eyeball was being turned inwards until finally the sight went and everything was blank. As to the amount of G. one could stand he was rather under the impression that it was a question of training and that one gets used to it as the training progressed. At the beginning of the training 4 G. was about the figure, but a week or two before the race the pilots could stand 5 or 6 G. without noticing any blacking out at all. As to the corset, the use of such an appliance again was very much a matter of training and strengthening the belly-muscles. His own view was that the corset instead of being any assistance might be rather disconcerting to a pilot, especially if in the middle of his turn the corset suddenly inflated and the pilot felt the pressure come on, and the extra cramped feeling rather upset the feel of his turn. Finally, as to the question of limiting speed, it would be interesting to know at what sort of speed the effect of heat due to air friction began to make itself felt and whether this effect is becoming almost noticeable at the speeds now obtained.

Mr. JAQUES: As one who for a number of years had been closely associated with the mechanical side of administering oxygen, he had listened with great interest to the outline given by the author of the medical aspects of the problem. The statement that the safe limit of altitude without oxygen was about 15,000ft. appeared to be confirmed by the fact that in the course of a fair amount of experience in the rarefaction chamber at Farnborough he had always felt quite happy with oxygen up to altitudes exceeding 30,000ft., but without oxygen even at 18,000ft. he and others in the chamber had experienced discomfort if they had to do even a small amount of exercise such as climbing into a cockpit or stooping.

With regard to the statements that had been made that the present method of administering oxygen was extremely wasteful, perhaps it would not be out of place if he mentioned that attention had been directed only recently to this point because there had been other troubles to overcome, such as the fact that when altitudes of over 25,000ft. were attained it had been found that a very small quantity of moisture in the oxygen—a quantity even less than that which commercially had been considered as pertaining to dry oxygen—led to trouble, and for quite a considerable time energies had been devoted to overcoming it. Having overcome, as was believed, that trouble, attention was now being turned to the other problem of reducing oxygen wastage.

Flight-Lieut. W. E. P. JOHNSON: He would like to ask one or two questions, not in any critical spirit and, indeed, one of them would be in a very

ignorant spirit. It would be interesting to know if any experiments had been made using ozone instead of oxygen and what the absorption—or whatever the right term was—of ozone in hæmoglobin was, because it seemed to him that possibly some allotropic form of oxygen might be found which might be absorbable in the same way as CO_2 or something of the kind, and which would be extremely useful. Further, he would like to know more about the incidence of the differences in blood pressure distribution over the body, which apparently was of some importance; at all events pilots were examined very carefully from this point of view. Regarding the body as a U tube it seemed to him that any severe acceleration must result in these differences being exaggerated in proportion to the G. imposed, and from what had been said in the discussion it might be important to consider the differences of pressure. A further small point was that the limit of altitude mentioned in the paper did not seem quite compatible with the altitudes at which the pilots were known to have fought during the war, and that was a thing which had always mystified him a great deal. People talked apparently quite truly of having fought at 22,000ft., and presumably exerted themselves at that great height.

Lieut.-Commander C. N. Colson, R.N.: Had any experiments been carried out with the pilot in any other position than the normal during tight turns—such as the horizontal position—and what effects had been felt from the G. imposed? In view of the lecturer's explanation of "blacking out" it would appear that this could be established as the correct explanation, or the reverse, by a series of experiments with an observer in the prone position; both on his face and on his back. It could then be ascertained whether he "blacked out" at the same time as the pilot.

Wing-Commander Rippon (President of the R.A.F. Central Medical Board): He expressed his gratitude to the Society for raising the subject which had been discussed, and for the opportunity of having Sir Leonard Hill, Capt. Uwins, and the other speakers, from whom he had learned a great deal.

As was fairly well known, the Medical Board had a standard of physical fitness for pilots which was laid down during the war as the result of the pioneer work of Sir Leonard Hill, the late Group-Capt. Flack, and the Air Medical Investigation Committee.

He wished to emphasise that there had been no material change in the physiological tests on the standard of fitness.

Referring to Capt. Uwins' record flight, he saw that the important point to realise was that any pilot who was up to the standard required for his "B" Licence, or the A1 Category of the R.A.F., could be relied on to fly at 18,000ft. without oxygen—and at higher altitudes, it was simply a matter of an efficient oxygen equipment.

Lieut.-Col. G. I. Jones, Chief of the Medical Division of the U.S. Army Air Corps (*communicated*): Wing-Commander Marshall has treated in an instructive manner a subject in physiology which has an important bearing on the capacity of man to successfully perform flying tasks at high speeds and altitudes.

The aspirations of man to attain high speeds and heights have resulted in mechanical achievements beyond physical endurance or security, in the state of our present knowledge.

His is a worthy contribution to the literature of human problems of aviation and a stimulus to further research in bridging the (now widening) gap between the human limitations to withstand the effect of directional changes at high speeds and the physiological effects of the higher altitudes. The physiological effect of directional changes at high speeds and ascent to higher altitudes is based upon known physical laws or phenomena. The physiological phenomena are reasonably well understood. Anoxemia (oxygen want) is a physiological

phenomenon clearly explained by the physical laws of pressure of compound gases, one of which is vital to metabolism and life. The physiological effects of directional changes at high speeds (he believed the same effects would result from prolonged flight at speeds beyond 300 m.p.h.) are based on indisputable physical laws of gravity and centrifugal force in which a stable vital fluid is affected.

Physically the explanation of anoxemia (oxygen want) lies in the availability of oxygen as determined by the valid laws applied to the absorption, partial pressure and solubility of gases. Physiologically relative oxygen want is determined by partial pressures in the alveolar air and that in the tissues. The whole syndrome of anoxemia as applied to higher altitude effects, both the incipient effects and the development of unconsciousness, is clearly a CO_2 intoxication and may be better so called.

The solution lies in research and the adoption of appliances to subject the flier to relatively the same atmospheric environment at heights beyond 15,000ft. as those below 18,000ft., which will permit the comfortable and secure performance of physical tasks in flying. It is reassuring to have the very positive prohibition to flights at heights beyond 15,000ft. for the reasons made obvious throughout this study that " individuals both differ and vary " and that " no pilot can be quite certain while flying that the necessity of carrying out some physically strenuous manœuvre . . . cannot possibly rise."

The points of attempt at physiological adaptability to changes of environment are pertinent, particularly the promotion of oxygen want and physical effort, because of increased respiratory rate and depth, especially when the rate of ascent is rapid. The injunction to gradual ascent beyond 10,000ft. is important. He held the view that the length of time spent at 15,000 to 20,000ft. also has a direct bearing on the occurrence of incidence of oxygen want.

As Wing-Commander Marshall has stated, the solution of the flier's environmental adaptation to heights beyond 15,000ft. is " to increase the partial pressure of oxygen." All of the disadvantages of the mask and cylinder lie in imperfections in the apparatus which it is believed will be corrected when the advantages of aircraft operation at higher altitudes necessitate more general use.

It would appear possible to develop an apparatus for mask or sealed cockpit use by which oxygen could be automatically delivered to mask or cockpit in quantities which would assure a uniform and constant partial pressure of oxygen.

The experience of the Medical Service with the U.S. Army Air Corps shows that the habitual practice of a relatively precipitate descent and ascent contribute to the gradual occurrence of deafness and probable unsteadiness of station due to reflex labyrinthine disturbance. This, however, is a less conspicuous cause of progressive deafness than the (remediable) vibratory, osseous conducted, engine and propeller noises.

The theory generally accepted by flight surgeons of the U.S. Army explains the phenomenon of " blacking out " as essentially due to centrifugal force and producing cerebral anæmia with resulting very momentary loss of consciousness. The wearing of a broad and tightly buckled belt devised to increase intra-abdominal pressure would be a wise practice for fliers whose missions require banks, turns, and dives at high speeds as a protection against " blacking out."

Experiments have been made on " centrifuging " dogs, *i.e.*, spinning them on a wheel, with the result that some of them actually showed injury to the brain resulting from its being violently pressed against the skull. So, in addition to the effects of cerebral anæmia, more serious and more permanent injury in banking and turning at high velocities may come from actual trauma to cerebral substance. Abrupt banks and turns at high speeds should be interdicted. Pylons used at competitions may be placed in triangular formation so as to increase the angle of directional change in flight.

The phenomenon of " redding out " is essentially and solely ocular in origin due to postural congestion of the vascular retina.

Wing-Commander Marshall has added conviction to the fact " that the range of environment in which humans can function is not unbounded." It is past time to give more attention to the study and development of " artificial aids whereby these natural boundaries may be greatly enlarged," and may he comment that these aids should be not only effective, but comfortable and have the full confidence of the user.

Reply to Discussion

In the short time available he would do his best to reply to the many points that had been raised, but if he omitted anything he hoped it would not be put down to his incompetence—although that was undoubted—nor to discourtesy, which was not intended, but to the fact that he had found it very difficult to keep pace with the questions raised in making his notes.

First, with regard to the Chairman's comments, it was pleasing to know that he supported the ideas set out in the lecture with regard to the pressure in an adiabatic cockpit. It was also desirable from a medical standpoint to keep the pressure difference as low as possible and so largely to prevent or reduce the risk of leakage. There were other advantages and particularly one which had not been mentioned: suppose an accident occurred and the pilot had to take to his parachute, the fact that he had to alter his pressure from that of relatively high-pressure cockpit to that of the atmosphere would place him at a greater disadvantage than if he was in the cockpit at a pressure more closely approximating to that of the atmosphere.

The point, mentioned by the Chairman, of the wastefulness of oxygen supplies had been dealt with by Mr. Jaques in his reference to the steps now being taken to improve oxygen apparatus. He was also grateful for the Chairman's confirmation of what he believed were the correct G. figures, but he would deal with that point later.

Squadron Leader Haythornthwaite had commented on the fact that no mention had been made of the effect of oxygen starvation on the brain. As a matter of fact, the author had not mentioned this because his sole object had been to try to show what were the physiological limits, and any attempt to deal with other aspects such as oxygen starvation would have taken up too much time. There was a great deal that might be said with regard to that matter and a great deal more than he himself knew concerning the effect of oxygen starvation, not only on the brain but also on the other organs, but he had purposely not gone into these matters because he appreciated that he was addressing the Royal Aeronautical Society and not a medical body and did not want to have too much " doctor's shop " about his lecture. He proposed, therefore, to leave that point. The same speaker also pointed out that one's environment was constantly changing and that whilst we were protected against changes of temperature we were not protected against changes of pressure. The author submitted, however, that this was not wholly correct, because whilst we might not be positively protected against changes of pressure we were negatively protected in the sense that we were able to encounter large changes of pressure without any ill-effects, and the blood-saturation curve which he had shown indicated the manner in which we were protected against changes of pressure. It was, in fact, possible to ascend to considerable height, where the pressure approximated to about half of what it was on the ground, and still be able, after a fashion, to carry on. Squadron Leader Haythornthwaite also doubted whether the scoop would replace itself. That scoop was only a suggestion, and personally he felt that careful design would be capable of producing such a scoop capable of replacing itself at the proper moment. However, he

did not feel competent to reply further on that because it was not within his province.

The presence of Capt. Uwins was particularly gratifying to the author and it had been very kind of Capt. Uwins to attribute any part of his recent remarkable achievement to the little that the author had been privileged to do to help Capt. Uwins, though the part he had played had been grossly exaggerated. Knowing Capt. Uwins' views he had purposely refrained from mentioning them in the lecture, preferring to get them from Capt. Uwins himself at the meeting. They now knew that Capt. Uwins did not think 44,000ft. was the limit, but that he thought flying above 42,000ft. should be limited to 40 minutes or thereabouts. That was an opinion in which he concurred. As he had stated in his lecture, he did not think that 44,000ft. represented the limit of toleration, but he believed it was the point where danger became suddenly acute. It must be remembered that Capt. Uwins was an exceedingly competent high-altitude pilot who had been well informed by experience and precept as to what was reasonably likely to happen to him. Personally he would very gladly go up with Capt. Uwins to heights of many thousands of feet more than any other pilot, no matter how skilful, who had not Capt Uwins's special experience of the conditions met with at high altitudes and who was not so fully aware of the risks to be encountered and the manner in which they arrived. This latter was one of the most important points because it was not enough for a pilot to be told that something would happen at a certain height; he wanted to know also how he was going to know when it was about to happen. Oxygen want was very insidious and was likely to appear quite unexpectedly at the limit of toleration when the pilot, though perfectly well and happy, was really on the verge of collapse. One of the things which was done to help Capt. Uwins was that a colleague and himself took Uwins into the low-pressure chamber at Farnborough to demonstrate to him how easy it all was. That was the only time that Capt. Uwins went into the chamber and it was an unpleasant experience for everybody, because everything that could go wrong went wrong His colleague had fainted and on recovery was trying hard to throw off the oxygen mask, whilst he himself was equally firmly resolved that it should not come off and was trying to jam it on again. Whilst doing this he himself " passed out " and came-to a little later, to find himself standing up, holding his colleague's wrist, taking his pulse with a very solemn expression on his face and holding a stop-watch in his hand! In the meantime Capt. Uwins was at the other end of the chamber 20ft. away with a 5ft. length of oxygen pipe wondering " what A does now."

Whilst he would agree that it might be safe for Capt. Uwins to rush up to 47,000ft. and back again, he would not dare to say that it would be safe for anyone else to do this unless he had the equivalent of Capt. Uwins' experience. Incidentally, said the author, he should have mentioned his indebtedness to Capt. Uwins for the figures which had enabled him to produce the graph of his flight, which had been shown on the screen.

He was highly gratified to see Sir Leonard Hill. In regard to the many points mentioned by him, the question of vapour-pressure of water in the lungs being in fact rather lower than it was theoretically believed to be, had been purposely left out of the lecture in order to keep it as short as possible. This discrepancy, if accepted, would make a difference of something like 1,000ft. or possibly 1,500ft., and therefore he did not think that it seriously upset the figures. Sir Leonard Hill had kindly allowed him to be present at some experiments he was now undertaking with the assistance of Sir Robert Davis, and it was hoped to get some valuable information from these. Quite recently some French observers had been doing animal experiments in the le Bourget decompression chamber, sending animals up to 40,000ft. and bringing them down again without apparent injury in six seconds, though this was much faster than anything he would suggest should be applied to the human person.

Gas in the intestines, also mentioned by Sir Leonard Hill, was important, but he had not said very much about it because he did not wish to create undue alarm. However, as the subject had been raised, he might say that recently a subject in the decompression chamber had become seriously ill for a short time as the result of the expansion of intestinal gas, and the experiment had had to be abandoned. At the same time, on return to higher atmospheric pressures, the subject recovered quickly although he had a very bad colour indeed, a bluish grey. A curious feature of these experiments which emphasised the point he had made about the insidious nature of oxygen want was that when this subject showed signs of imminent collapse at 37,000ft. he protested that he was perfectly well and that the medical attention he was then given, when he was on the verge of fainting, was unnecessary.

With regard to the reference by Sir Leonard Hill to the wastefulness of certain methods of oxygen supply and to his opinion that the Mount Everest climbers would not be getting 1½ litres per minute, the apparatus in the design of which the author had participated did not involve the wastage of two-thirds suggested by Sir Leonard Hill, as it was of a reservoir type in which the oxygen was momentarily stored in the wide-bore delivery-tube, and he could assure Sir Leonard Hill that the climbers would get nearly 1½ litres of oxygen per minute.

It was more than gratifying to see such distinguished pilots as Wing-Commander Orlebar and Flight-Lieut. Stainforth present and to hear from Wing-Commander Orlebar that most of the Schneider pilots had had no trouble below 4½ G. The figure given in the lecture for the average onset of " blacking out " was 3½ G. to 4 G. and not 3 G. Flight-Lieut. Stainforth had stated that in his experience pilots experienced blacking out at about 4 G. at the beginning of training, but that this was reduced after training. These figures were all very much alike and it must be remembered that the Schneider pilots were, as the world well knew, really super-men of their category. They were not only very skilled, but they were in an exceedingly fine physical condition and trained for this particular work, so that he felt rather unrepentant about his 3½ to 4 G., because he regarded them still as reasonable figures at which one might expect flying to go on with a pilot who was not specifically trained. The lecture contained a reference to the cultivation of the body muscles to which Wing-Commander Orlebar had referred. As regards the corset—which the author hoped would not be known as " his " corset—he was pleased to know from Wing-Commander Orlebar that his 10-second suggestion was an under-estimate; a valuable piece of information. As Flight-Lieut. Stainforth had said, " blacking out " was a bad name for this phenomenon. It was really only a gradual suffusion of the visual field, but he used the term " blacking out " because it was the generally accepted term. In the same way " redding out " was a suffusion from the field of vision. Flight-Lieut. Stainforth had doubted whether the corset would be desirable for the pilot and suggested that it might disconcert him through suddenly blowing up. The author agreed that this would be most undesirable, but remarked that it need never occur, because both the speed and the extent of inflation were controllable and the corset could therefore be adjusted so as not to blow up too suddenly. It was also very pleasing to have the support of Mr. Jaques, although he had raised no points which called for answer.

The author had consulted Dr. Fisher, the Chief Medical Officer of the Department of Mines, about the maximum speed of descent in mine-shafts and had been informed that these were very much less than in the air and that no trouble had been experienced from this cause in mines.

The trouble with ozone, mentioned by Flt.-Lt. Johnson, was that it was very toxic, and that it was not a physiological substitute for oxygen. As to the question of the differences in blood pressure in different parts of the body and their significance at high altitudes, some blood pressure experiments were con-

templated at Farnborough, although personally he was satisfied that these differences were not significant.

The question of the heights at which airmen fought during the war was also raised by Flt.-Lt. Johnson. The formulæ on which the calibration of war-time altimeters had been based had since been corrected, and he believed he was right in saying that the disproportion was something in the nature of 2,000 to 3,000ft. when 20,000ft. up. Therefore, a man who during the war thought he was flying at about 20,000ft. was really only at about 17,000 to 18,000ft., and this accounted for some of the discrepancies. Again, to help account for the discrepancy there was the fact that the war pilot was not carrying out peace flying at this very great height. Most of these war-time 20,000ft. flights without oxygen were carried out by fighting pilots who were in great danger, and there was no doubt that this enabled men to go beyond the physiological boundaries of cold blood. There was, however, no reason to doubt the general veracity of these statements. Although it was true that some pilots flew at great heights during the war without any trouble, there were only too many who flew at great heights but who were no longer with us to tell us whether they felt any trouble or not. He did not suggest that this was the reason why these pilots were no longer with us, but in many cases it was at least conceivable.

In reply to Lieut. Commander Colson, the question of flying in attitudes other than normal was raised 10 or 11 years ago, but was turned down by pilots in general because, he believed, it was not regarded as practical at all. The obvious posture by which a high-speed pilot might avoid the effect of excessive G. was prone (face downward), as when bombing, but it was difficult to see ahead when lying in that position; indeed, he should have thought it was quite impossible.

In reply to the remarks by Lieut.-Col. Jones, Chief of the Medical Division of the United States Army Air Corps, the author desired to thank him for the interest he had shown.

He found it difficult to follow Col. Jones in the belief that prolonged straight flight at speeds beyond 300 m.p.h. would produce effects similar to those of changes of direction at high speed, since it appeared to him that once an organism is in a state of motion of uniform speed and direction, time alone would not suffice to produce physiological disturbance.

He agreed with Col. Jones that the length of time spent without oxygen above 15,000ft. was a factor in determining the onset of oxygen want and thought that in order to obviate the risk of very tight, high-speed turns in competition flying it would suffice if the turning pylons were arranged in pairs, not too far apart.

THE NATURE OF THE TORSIONAL STABILITY OF A MONOCOQUE FUSELAGE

BY

KATSUTADA SEZAWA

I. Introduction

Although the problem of the stability of a fuselage that is subjected to torsional force is important in connection with the case of light metal construction of an aeroplane in flight, the theoretical side of the problem does not seem to have received much attention. This is probably because of the difficulty of obtaining its mathematical solution even in the case where the fuselage is assumed to be a circular hollow cylinder. Thus, I studied the problem in assuming that the fuselage is a cylindrical shell for the first approximation. Southwell and Skan[1] have dealt with the stability of a plane elastic strip due to edge shearing forces, but their result cannot be applied to the problem of the cylindrical shell unless its length is very short. Schwerin[2] seems to be the only one who has written on the torsional stability of a cylindrical shell. Although his method of constructing the differential equations of the equilibrium of a cylindrical shell has been chiefly derived from Love's text book,[3] and appears correct in the main, yet owing to the certain apparent particularities on his part his solutions of equations are open to grave doubts. From the nature of the problem, equations of the cylindrical shell under torsion are not easy to solve. The trouble with my present problem was the difficulty in finding these solutions. However, I avoided the difficulty by tentatively applying the result of Southwell and Skan to the solutions of my differential equations by assuming these equations to be certain modifications of their case and then finding the solutions of these modified forms. However, even with this method of treatment, I had difficulties in my calculation, especially in finding the corrected roots of the equations of equilibrium that satisfy all boundary conditions.

So far as I am aware, no results of experimental studies on the torsional stability of a cylindrical shell have yet been published. I therefore investigated the buckling by means of experiments, in which cylindrical shells of indiarubber of various thicknesses and lengths are twisted in a specially designed apparatus and the critical torsional moments and the forms of the deformation of the shell are carefully observed. Although the experimental results have not shown perfect accord with the mathematical results, yet the two methods of investigation have shown a general tendency towards eventual agreement. The small discrepancies in numerical values between theory and experiment seem to be due to certain unknown physical phenomena related to buckling, to say nothing of possible flaws in the method of experiment or in its execution.

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[1] R. V. Southwell and Sylvia W. Skan. "On the Stability under Shearing Forces of a Flat Elastic Strip." *Proc. Roy. Soc., London*, **105** (1924), 582-607.

[2] E. Schwerin. "Die Torsionalstabilität des dünwandigen Rohres." *Proc. 1-int. Congr. Appl. Mech.* (Delft, 1924), 255-265; *Z.A.M.M.*, **5** (1925), 235-243.

[3] A. E. H. Love. *Mathematical Theory of Elasticity, 3rd ed.* (Cambridge, 1920), Chap. XXIV.

II. The Mathematical

Let us take the cylindrical co-ordinates x, r and ϕ. The axis of x coincides with the axis of the cylinder of radius a, the origin being at the middle point of the axis of the cylinder. Let u, v and w be the components of the displacement of a point on the shell in the directions x, ϕ and r. A uniform shearing force, whose intensity per unit arc length of the cross section is S_0, is applied to the ends of the cylinder. Let the induced normal and shearing forces per unit length of the sections in the directions x, ϕ and $x-\phi$ be T_1, T_2 and S. The resulting shearing force in direction $x-\phi$ will then be S_0+S. Let the radial shearing forces per unit length of the cross and longitudinal sections be N_1 and N_2, and the stress couples at these sections G_1 and G_2. Finally, let the torsional moment due to the stresses about an axis parallel to the generating lines of the cylinder be H. We have now the equations of equilibrium of the shell in the following forms:—

$$\partial T_1/\partial x+(1/a)\,\partial S/\partial\phi=0, \quad . \quad . \quad . \quad . \quad (1)$$

$$\partial S/\partial x+(1/a)\,\partial T_2/\partial\phi+N_2=0, \quad . \quad . \quad . \quad . \quad (2)$$

$$\partial N_1/\partial x+(1/a)\,\partial N_2/\partial\phi+(2/a)\,(\partial^2 w/\partial x\partial\phi-\partial v/\partial x)\,S_0=0, \quad . \quad . \quad (3)$$

$$\partial H/\partial x-(1/a)\,\partial G_2/\partial\phi+N_2=0, \quad . \quad . \quad . \quad (4)$$

$$\partial G_1/\partial x-(1/a)\,\partial H/\partial\phi-N_1=0, \quad . \quad . \quad . \quad . \quad (5)$$

which can readily be deduced from the formulæ in Love's text book.[4] (1), (2) and (3) of the above equations correspond to the first, second and third equations of (45) in Love's work, while (4) and (5) of these equations are deduced from the first and second of (46) in the same book. S_1 and S_2 in Love's case should be taken here as $S_1=-S_2=S$, while small quantities higher than the second order are omitted in the derivation of equations from (1) to (5) inclusive.

Now, substituting N_2 from (4) in (2), and N_2 and N_1 from (4) and (5) in (3), we obtain

$$\partial T_1/\partial x+(1/a)\,\partial S/\partial\phi=0, \quad . \quad . \quad . \quad . \quad (6)$$

$$\partial S/\partial x+(1/a)\,\partial T_2/\partial\phi-(1/a)\,\partial H/\partial x+(1/a^2)\,\partial G_2/\partial\phi=0, \quad . \quad . \quad (7)$$

$$\partial^2 G_1/\partial x^2-(2/a)\,\partial^2 H/\partial x\partial\phi+(1/a^2)\,\partial^2 G_2/\partial\phi^2+(2/a)\,(\partial^2 w/\partial x\partial\phi-\partial v/\partial x)\,S_0=0 \quad (8)$$

From the general theory of a thin cylindrical shell we find that

$$\left.\begin{aligned}
T_1&=(12\,D/h^2)\,\{\,\partial u/\partial x+(\sigma/a)\,(\partial v/\partial\phi+w)\,\},\\
T_2&=(12\,D/h^2)\,\{\,(1/a)\,(\partial v/\partial\phi+w)+\sigma\,\partial u/\partial x\,\},\\
S&=(12\,D/h^2)\,(1-\sigma)/2\;\{\,\partial v/\partial x+(1/a)\,\partial u/\partial\phi\,\},\\
G_1&=-D\,\{\,\partial^2 w/\partial x^2+(\sigma/a^2)\,(\partial^2 w/\partial\phi^2-\partial v/\partial\phi)\,\},\\
G_2&=-D\,\{\,(1/a^2)\,(\partial^2 w/\partial\phi^2-\partial v/\partial\phi)+\sigma\,\partial^2 w/\partial x^2\,\},\\
H&=D\,(1-\sigma)/a\,(\partial^2 w/\partial x\partial\phi-\partial v/\partial x),
\end{aligned}\right\} \quad . \quad . \quad (9)$$

where $D=Eh^3/12\,(1-\sigma^2)$; E is Young's modulus, σ Poisson's ratio, and h the thickness of the cylinder wall.

In order to solve equations (6), (7), (8) and (9), simultaneously, we put

$$\left.\begin{aligned}
u&=A\sin\,(mx/a+n\phi),\\
v&=B\sin\,(mx/a+n\phi),\\
w&=C\cos\,(mx/a+n\phi),
\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (10)$$

in which A, B and C are arbitrary constants, while m and n, which may be either real or complex, will presently be determined. Substituting (10) in (6), (7) and (8), either directly or by means of (9), and eliminating A, B, C, we get the following determinantal equation:—

$$\begin{vmatrix}
m^2+(1-\sigma)\,n/2, & -12\,mn\,(1+\sigma)/2, & 12\,\sigma m\\
mn\,(1+\sigma)/2, & -\{\,12\,m^2\,(1-\sigma)/2+12\,n^2\,\}, & 12\,n\\
0, \;(2-\sigma)\,m^2n+n^3+2\,mS_0a^2/D, & -(m^4+2\,m^2n^2+n^4+2mnS_0a^2/D) &
\end{vmatrix}=0. \quad . \quad (11)$$

[4] Love. *loc. cit.* Chapter XXIV (45), (46), (24), (25).

Expanding this determinant, we get

$$-\psi\,(m^2+n^2)^2+\{\,(4-\sigma^2)\,m^4n^2+2\chi\,(2+\sigma)\,m^3n+4\,m^2n^4 +2\chi mn^3+n^5\,\}=0, \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

in which

$$\left.\begin{aligned}\psi&=m^4+2m^2n^2+n^4+2mnS_0a^2/D,\\ \chi&=S_0a^2/D.\end{aligned}\right\} \quad . \quad . \quad . \quad (13)$$

As $2\pi a/n$ is the wave length of the wrinkles or corrugations along the circumference of the cylindrical shell, n gives the number of lobes on the surface of that shell. By giving a certain value to n and solving equation (12) with respect to m, we should get eight roots, each of which involves S_0a^2/D. On substituting these values of m in the expressions for u, v and w in (10) in the following forms,

$$\left.\begin{aligned}u&=\sum_{\mathrm{p}} A_{\mathrm{p}}\sin\,(m_{\mathrm{p}}x/a+n\phi),\\ v&=\sum_{\mathrm{p}} B_{\mathrm{p}}\sin\,(m_{\mathrm{p}}x/a+n\phi),\\ w&=\sum_{\mathrm{p}} C_{\mathrm{p}}\cos\,(m_{\mathrm{p}}x/a+n\phi),\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (14)$$

and then applying these expressions for u, v and w to the prescribed boundary conditions at both ends of the shell, we obtain the values of $\chi\,(=S_0a^2/D)$, corresponding to the assumed n. These values of χ give the shearing force S_0 at the critical state of loss of stability in the vibratory motion of the shell having n lobes. In the same way we may assume different values for n and find χ corresponding to these n's. The mode of the vibration that gives the smallest value to χ undoubtedly corresponds with the buckling condition of the shell. The values of S_0 and n in such a case give us the critical force and the corresponding number of lobes.

Although the foregoing discussion is theoretically correct, its computation is not easy for the reason that equation (12) is of the eighth degree in m. The difficulty is enhanced because the value of m contains the unknown quantity S_0a^2/D, and also because m is not necessarily real, some m's being imaginary, and even complex. We have therefore adopted a method by which, assuming the equation in m to be certain modifications of the case $a=\infty$ (due to Southwell and Skan), we tentatively seek the solutions of these modified forms.

To simplify the problem we take $\sigma=\frac{1}{2}$; write $m=\lambda a/b$, $n=ka/b$ and $\phi'=\chi\,b^2/a^2$ and put these in (12). We then have

$$-(\lambda^4+2k^2\lambda^2+2k\lambda\phi'+k^4)\,(\lambda^2+k^2)^2 +(3{\cdot}75\,k^2\lambda^4+5\phi'k\lambda^3+4k^4\lambda^2+2\phi'k^3\lambda+k^6)\,(b/a)^2=0. \quad . \quad (15)$$

When $b/a=0$ this becomes

$$\lambda^4+2k^2\lambda^2+2k\lambda\phi'+k^4=0, \quad . \quad . \quad . \quad . \quad (16)$$

so that our equation has been reduced to a modified form of that of Southwell and Skan.[5] The solutions of (16) are $\lambda=\lambda_0{}^1$, $\lambda_0{}^2$, $\lambda_0{}^3$ and $\lambda_0{}^4$, the corresponding ϕ' being ϕ'_0. The solutions of equation (15) may be written in the forms:—

$$\lambda=\lambda_0{}^1+\lambda_1{}^1,\lambda=\lambda_0{}^2+\lambda_1{}^2,\lambda=\lambda_0{}^3+\lambda_1{}^3,\lambda=\lambda_0{}^4+\lambda_1{}^4; \quad . \quad . \quad (17)$$

while the corresponding ϕ' may also be written

$$\phi'=\phi'_0+\phi'_1. \quad . \quad . \quad . \quad . \quad . \quad (18)$$

Substituting (17) and (18) in (15) and applying relation (16) we get

$$\{\,(4\lambda_0{}^3+4\lambda_0k^2+2k\phi'_0)\,\lambda_1+2\lambda_0k\phi'_1\,\}\,(\lambda_0{}^2+k^2)^2 -(3{\cdot}75\,k^2\lambda_0{}^2+5k\lambda_0{}^3\phi'_0+4k^4\lambda_0{}^2+2k^3\lambda_0\phi'_0+k^6)\,(b/a)^2=0, \quad . \quad (19)$$

where λ_0 takes four values, namely, $\lambda_0{}^1$, $\lambda_0{}^2$, $\lambda_0{}^3$ and $\lambda_0{}^4$, while ϕ'_0 is unique for these different values of λ_0. Equation (19) enables us to find the various groups of λ_1 and ϕ'_1 for each value of $\lambda_0{}^1$, $\lambda_0{}^2$, $\lambda_0{}^3$ and $\lambda_0{}^4$. From these combinations

[5] *loc. cit.*

of λ_1 and ϕ'_1 we select the one that satisfies the boundary conditions of the shell. The boundary conditions are shown below.

When both ends of the shell are clamped the conditions are such that

$$x=\pm b\,;\ w=0,\ \partial w/\partial x=0: \quad . \quad . \quad . \quad . \quad (20)$$

and, when these ends are supported the conditions are

$$x=\pm b\,;\ w=0,\ \partial^2 w/\partial x^2 \backsim 0. \quad . \quad . \quad . \quad (21)$$

If we substitute the expressions of (14), where $p=1$, 2, 3 and 4, and $m=\lambda a/b$, in (20) and (21), we obtain for the case of the clamped ends

$$\begin{aligned}&(\lambda^1-\lambda^2)\,(\lambda^3-\lambda^4)\sin(\lambda^1-\lambda^3)\sin(\lambda^2-\lambda^4)\\&=(\lambda^1-\lambda^3)\,(\lambda^2-\lambda^4)\sin(\lambda^1-\lambda^2)\sin(\lambda^3-\lambda^4),\end{aligned} \quad . \quad . \quad . \quad (22)$$

and for the case of the supported ends

$$\begin{aligned}&(\lambda^{1_2}-\lambda^{2_2})\,(\lambda^{3_2}-\lambda^{4_2})\sin(\lambda^1-\lambda^3)\sin(\lambda^2-\lambda^4)\\&=(\lambda^{1_2}-\lambda^{3_2})\,(\lambda^{2_2}-\lambda^{4_2})\sin(\lambda^1-\lambda^2)\sin(\lambda^3-\lambda^4).\end{aligned} \quad . \quad . \quad (23)$$

For convenience we may write

$$\lambda^1=\alpha+\beta,\ \lambda^2=\alpha-\beta,\ \lambda^3=-\delta+i\gamma,\ \lambda^4=-\delta-i\gamma, \quad . \quad . \quad (24)$$

and substituting them in (22) and (23), we get

$$2\beta\gamma\,[\cos 2\beta\cosh 2\gamma-\cos 2\,(\alpha+\delta)]=[(\alpha+\delta)^2-\beta^2+\gamma^2]\sin 2\beta\sinh 2\gamma; \quad (25)$$

and

$$\begin{aligned}&8\alpha\beta\gamma\delta\,[\cos 2\beta\cosh 2\gamma-\cos 2\,(\alpha+\delta)]\\&=[(\alpha^2-\delta^2)^2+(\beta^2+\gamma^2)^2+2\,(\alpha^2+\delta^2)\,(\gamma^2-\beta^2)]\sin 2\beta\sinh 2\gamma,\end{aligned} \quad . \quad (26)$$

for the two above-mentioned cases of end conditions. In (25) and (26), α, β, γ and δ are real quantities, and $\alpha=\delta$ when $b/a=0$. Hence $\lambda_1{}^1$ and $\lambda_1{}^2$ may be deduced as certain functions of ϕ'_1 directly from (19), $\lambda_0{}^1$ and $\lambda_0{}^2$ having been taken from the result of Southwell and Skan. λ^3 and λ^4 are, however, complex, so that we write

$$\left.\begin{aligned}\lambda^3&=-(\alpha_0+\delta_1)+i\,(\gamma_0+\gamma_1),\\ \lambda^4&=-(\alpha_0+\delta_1)-i\,(\gamma_0+\gamma_1),\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (27)$$

which, when substituted in (19), give

$$\begin{aligned}&[4\delta_1\,(\alpha_0{}^3-3\alpha_0\gamma_0{}^2+k^2\alpha_0+k\phi'_0/2)+2\alpha_0 k\phi'_1\\&-4\gamma_1\,(3\alpha_0{}^2\gamma_0-\gamma_0{}^3+k^2\gamma_0)]\,(\alpha_0{}^4-6\alpha_0{}^2\gamma_0{}^2+\gamma_0{}^4+2\,(\alpha_0{}^2-\gamma_0{}^2)\,k^2+k^4)\\&-[4\delta_1\,(3\alpha_0{}^2\gamma_0-\gamma_0{}^3+k^2\gamma_0)+4\gamma_1\,(\alpha_0{}^3-3\alpha_0\gamma_0{}^2+k^2\alpha_0+k\phi'_0/2)\\&+2\gamma_0 k\phi'_1]\,(4\alpha_0{}^3\gamma_0-4\alpha_0\gamma_0{}^3+4\alpha_0\gamma_0 k^2)\\&=[3{\cdot}75\,k^2\,(\alpha_0{}^4-6\alpha_0{}^2\gamma_0{}^2+\gamma_0{}^4)+5k\phi'_0\,(\alpha_0{}^3-3\alpha_0\gamma_0{}^2)\\&+4k^4\,(\alpha_0{}^2-\gamma_0{}^2)+2k^3\phi'_0\alpha_0+k^6]\,(b/a)^2, \quad . \quad . \quad . \quad (28a)\end{aligned}$$

$$\begin{aligned}&[4\delta_1\,(3\alpha_0{}^2\gamma_0-\gamma_0{}^3+k^2\gamma_0)+4\gamma_1\,(\alpha_0{}^3-3\alpha_0\gamma_0{}^2+k^2\alpha_0+k\phi'_0/2)\\&+2\gamma_0 k\phi'_1]\,(\alpha_0{}^4-6\alpha_0{}^2\gamma_0{}^2+\gamma_0{}^4+2\,(\alpha_0{}^2-\gamma_0{}^2)\,k^2)\\&+[4\delta_1\,(\alpha_0{}^3-3\alpha_0\gamma_0{}^2+k^2\alpha_0+k\phi'_0/2)+2\alpha_0 k\phi'_1\\&-4\gamma_1\,(3\alpha_0{}^2\gamma_0-\gamma_0{}^3+k^2\gamma_0)]\,(4\alpha_0{}^3\gamma_0-4\alpha_0\gamma_0{}^3+4\alpha_0\gamma_0 k^2)\\&=[-3{\cdot}75\,k^2\,(4\alpha_0{}^3\gamma_0-4\alpha_0\gamma_0{}^3)+5k\phi'_0\,(3\alpha_0{}^2\gamma_0-\gamma_0{}^3)\\&+8k^2\alpha_0\gamma_0+2k^3\phi'_0\gamma_0]\,(b/a)^2. \quad . \quad . \quad . \quad . \quad (28b)\end{aligned}$$

From (28a) and (28b) δ_1 and γ_1 can be determined, α_0 and γ_0 being from the result of Southwell and Skan. Thus, we obtain from (19) and (28)

$$\left.\begin{aligned}\alpha&=\{\,(\lambda_0{}^1+\lambda_1{}^1)+(\lambda_0{}^2+\lambda_1{}^2)\,\}/2, & \beta&=\{\,(\lambda_0{}^1+\lambda_1{}^1)-(\lambda_0{}^2+\lambda_1{}^2)\,\}/2,\\ \delta&=\alpha_0+\delta_1, & \gamma&=\gamma_0+\gamma_1.\end{aligned}\right\} \quad . \quad (29)$$

Substituting (29) in (25) and (26), we get an equation in ϕ'_1 for both cases of boundary conditions. Solving this equation in ϕ'_1, we finally obtain

$$\phi'=\phi'_0+\phi'_1. \quad . \quad . \quad . \quad . \quad . \quad (30)$$

As the reader will notice, these processes from (17) to (30) have been applied to various values of n and b/a. When b/a becomes so large that the approximate formula of (19) becomes unreasonable, the calculation should not be carried further.

We have calculated the cases where $b/a=1$ and 2 and $\sigma=\frac{1}{3}$ for different values of n. Figs. 1 and 2 give us systems of curves showing S_0b^2/D with $2\pi/k$ as base, the last term $2\pi/k$ being the central angle corresponding to the wave length of the corrugations. Fig. 1 represents the case of the clamped ends and Fig. 2 that of the supported ends.

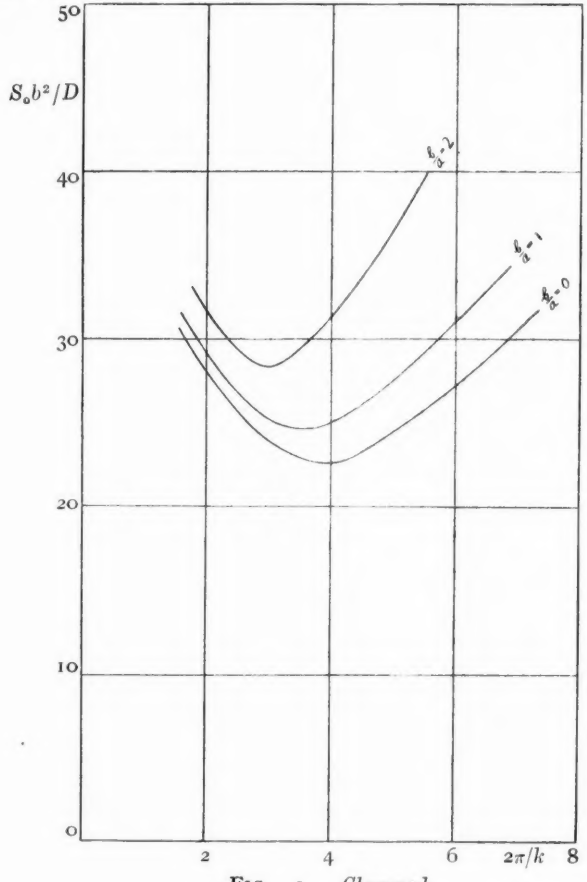

FIG. 1. *Clamped.*

The values of α, β, γ, δ, $2\pi/k$, b/a, ϕ'_1 and ϕ' which are obtained in the course of calculation, are tabulated below:—

TABLE I.

BOTH ENDS CLAMPED.

	α	−2.691	−2.191	−1.950	−1.847
	β	1.727	1.771	1.799	1.820
	$-\delta$	2.724	2.254	2.113	1.865
$b/a=1$	γ	7.106	5.530	4.174	3.761
	$2\pi/k$	1.60	2.29	3.20	5.33
	ϕ'_1	0.82	1.11	1.62	3.22
	ϕ'	36.02	26.85	23.81	29.00

	α	−2.696	−2.131	−1.903	−1.812
	β	1.725	1.760	1.768	1.797
	$-\delta$	2.717	2.382	2.512	2.132
$b/a=2$	γ	7.563	6.230	5.631	4.875
	$2\pi/k$	1.60	2.29	3.20	5.33
	ϕ'_1	3.24	4.21	6.18	12.83
	ϕ'	38.44	29.91	28.37	38.61

TABLE II.

BOTH ENDS SUPPORTED.

	α	−2.181	−1.830	−1.563	−1.466
	β	1.487	1.457	1.440	1.420
	$-\delta$	2.271	1.965	1.625	1.509
$b/a=1$	γ	5.860	4.625	3.810	3.440
	$2\pi/k$	2.00	2.67	4.00	5.33
	ϕ'_1	0.70	1.04	2.16	3.17
	ϕ'	24.47	18.43	15.79	16.38
	α	−2.114	−1.778	−1.543	−1.491
	β	1.501	1.485	1.479	1.485
	$-\delta$	2.477	2.321	2.025	1.662
$b/a=2$	γ	6.575	5.482	4.893	4.769
	$2\pi/k$	2.00	2.67	4.00	5.33
	ϕ'_1	2.98	4.37	7.77	11.70
	ϕ'	26.75	21.76	21.40	24.91

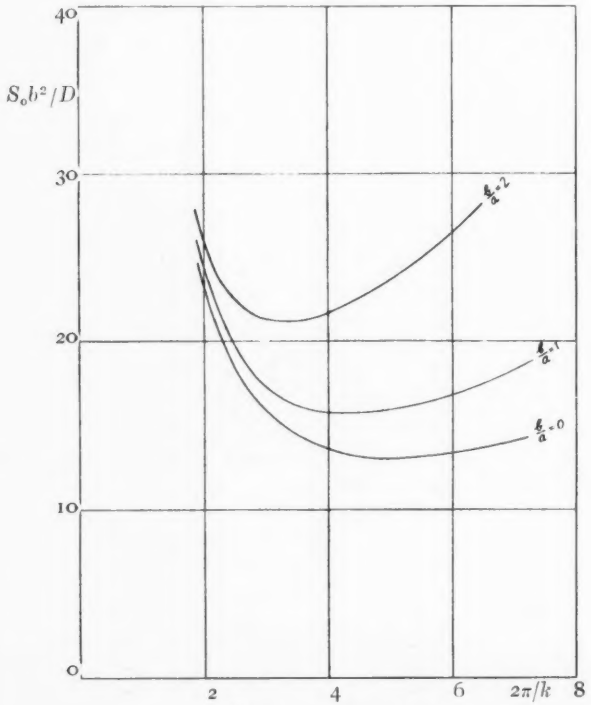

FIG. 2. *Supported.*

As has already been stated, the buckling of the shell occurs at the respective minimum values of $S_0 b^2/D$ for the ratios of b/a, as shown in Figs. 1 and 2, so that it may easily be seen from these two figures that the shearing force S_0 and $2\pi/k$ are as follows:—

TABLE III.

Ends.	Clamped Ends.			Supported Ends.		
b/a	0	1	2	0	1	2
$S_0 b^2/D$	22.2	23.9	27.8	13.2	15.7	21.2
$S_0 a^2/D$	—	23.9	6.95	—	15.7	5.30
$2\pi/k$	3.4	3.1	2.8	5.0	4.2	3.4

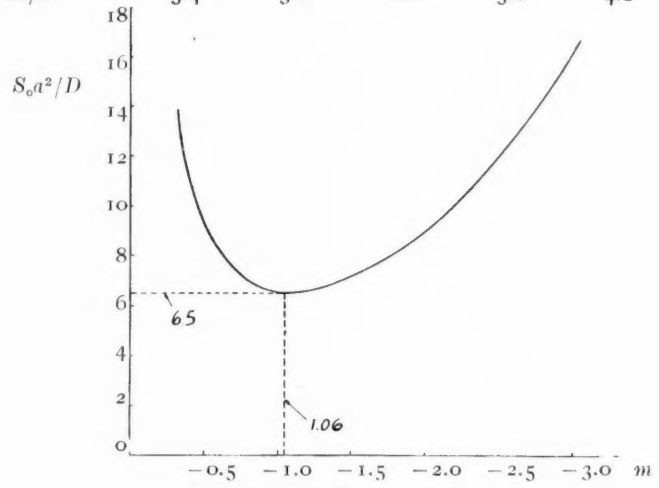

FIG. 3.

Now, the problem of the buckling of a very long cylindrical shell can also be treated in a simple manner. The end conditions have little influence on the deformation, and the corrugations or creases of the shell wall naturally take a helical form, so that we have to find from equation (12) the minimum of S_0 that corresponds to different values of m and n (total number of corrugations). Again, from elementary principles, we may assume $n=1, 2, 3. \ldots$ The case $n=1$ will rarely occur in an actual problem. As to the remaining n, the case $n=2$ obviously gives the smallest value of S_0. We have, therefore, from (12) by putting $n=2$ and $\sigma=1/2$,

$$S_0 a^2/D = \{ (3m^2+8)(5m^2+8) - (m^2+4)^4 \} / 2m (2m^4+11m^2+24). \qquad (31)$$

The minimum of S_0 corresponding to the different values of m may be obtained from the differentiation:—

$$d(S_0 a^2/D)/dm = 0; \quad . \quad . \quad . \quad . \quad . \qquad (32)$$

but, as the process is somewhat complicated, we calculate the values of $S_0 a^2/D$ for the various values of m directly from (12) and select the minimum of these values. The corrugations being helical, it is sufficient to consider only the case of m being real. The result thus obtained is shown in Fig. 3.

It will be seen from this figure that the minimum of $S_0 a^2/D$ is 6.50, and occurs when $m=1.06$ ($n=2$). This corresponds to the case of a helix with an angle $\theta=27^\circ\ 30'$, inclined to the axis of the cylinder. For higher values of n, S_0 becomes greater, so that the minimums of the respective $S_0 a^2/D$ curves correspond to such cases of n have no significance so far as the critical state of the

buckling is concerned. A comparison of the results in Figs. 1, 2 and 3 shows that the condition of the buckling near $b/a=2$ is practically the same as that for $b/a=\infty$.

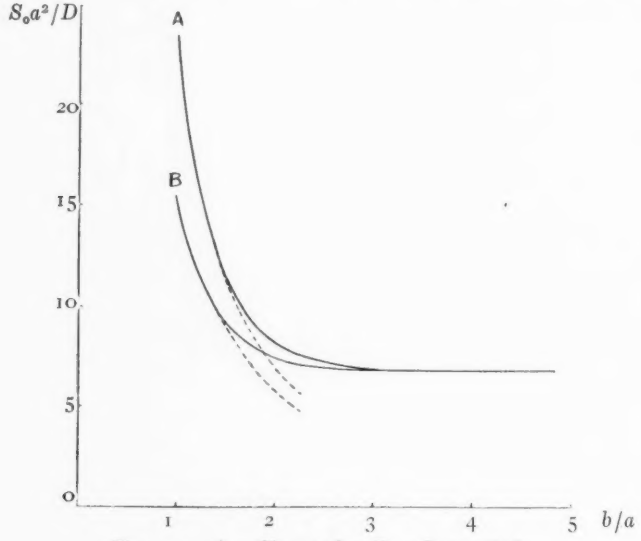

FIG. 4. *A. Clamped. B. Supported.*

Thus, we get the relation between the critical values of the shearing force S_0 and the ratio of b/a, as in Fig. 4. In this figure, curves A and B were derived from the results in Figs. 1 and 2, and through close interpolations among the respective curves in these figures. These curves A and B have been joined to the asymptotic straight line that indicates the critical values of S_0 for $b/a=\infty$.

Although Fig. 4 enables us to know the critical values of S_0 for the different ratios of b/a, we might tabulate the results, numerically, though comparatively roughly, together with the number of the lobes with their inclination to the axis of the cylinder.

TABLE IV.

Ends.	Clamped Ends.				Supported Ends.			
b/a	0	1	2	∞	0	1	2	∞
S_0b^2/D	22.2	23.9	27.8	—	13.2	15.7	21.2	—
S_0a^2/D	—	23.9	6.95	6.50	—	15.7	5.30	6.50
n	$(2\pi/k=3.4)$	2	2	2	$(2\pi/k=5.0)$	2	2	2
θ	38°	—	—	27° 30′	43°	—	—	27° 30′

III. THE EXPERIMENTAL

The experimenting apparatus is shown in Fig. 5. Two gunmetal discs are mounted on a steel shaft turned by worm gear; one disc at the upper end of the shaft and the other at a distance below it. The upper disc rotates about the shaft without sensible friction by means of radial and thrust ball bearings. It may be fixed at will by a clamp screw, while the lower disc not only rotates but also slides on the same shaft. The upper and lower ends of a cylindrical shell of indiarubber sheeting are clamped to the discs by means of steel collars. A number of these hollow rubber cylinders in various sizes are used in my experiment. The upper disc has a groove around its circumference, and around it is

wound a wire which passes over a system of pulleys placed in suitable positions, weight pans being suspended at the end of the overhanging wire. To the same disc is fitted another wire with balance weights hanging at the end.

As soon as the hanging weights begin to pull, corrugations or creases begin to form on the rubber surface as a consequence of the twisting of the cylinder. These corrugations, as they form, are observed through a microscope sliding along a vertical brass column that is a part of the frame of the apparatus. The magnification employed is 25×10. The unevennesses of the surface at load and at no load are measured by the vernier scale. The angle of rotation of the disc

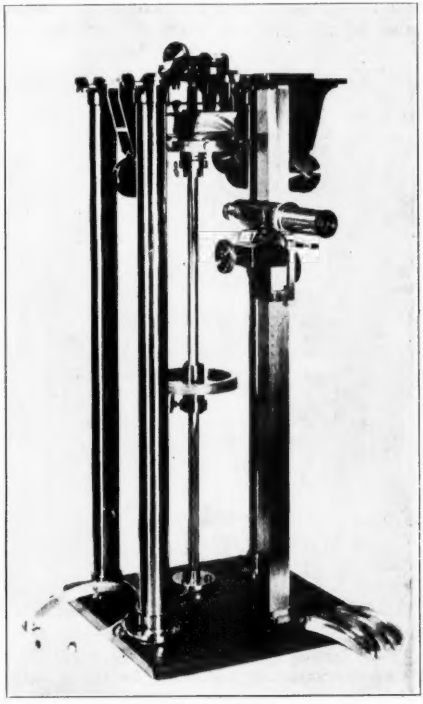

FIG. 5.

system and the distance of the vertical sliding of the microscope, respectively, are read off from the scales marked on the discs and on the vertical brass column.

I have a high opinion of rubber as suitable material for experiments in problems relating to buckling, the reasons for which will become clear as I proceed. Now the Young's modulus of the rubber in the present experiment was found to be $3.50\ (1 \pm 0.1) \cdot 10^7$ C.G.S., while the Poisson's ratio was assumed, roughly, to be 1/2. For measuring Young's modulus of the rubber I prepared test pieces of the rubber sheets by cutting them in various directions. The values of this modulus whether in axial, transverse, or oblique direction of the cylinder do not differ much; the difference being only ten or twenty per cent., so that I shall not be very wrong in assuming the material to be isotropic. The diameter of the cylinder is 100 mm., while its effective length is varied from 50 mm. to 200 mm., the thickness of the rubber ranging from 0.60 mm. to 2.80 mm.

Briefly, the experiment was conducted as follows. After the unevenness of the surface of the rubber has been observed, the screw that pushes the upper disc against the shaft is clamped, and some weights are placed on the scale pan. The screw is now unclamped, when, with the revolution of the upper disc, very faint corrugations make their appearance. At first, these corrugations are not easily discernible; changing their forms, they travel from one part of the rubber surface to another. I clamp again the screw with the shell thus twisted and remove the weights. If the deformation of the corrugation is now measured through the microscope, we get the relation between the deformation and the shearing force due to the applied load. In this way I may obtain the relations just stated for a wide range of loading. When the loading reaches a certain stage, the phenomenon of the critical state of buckling takes place. At this

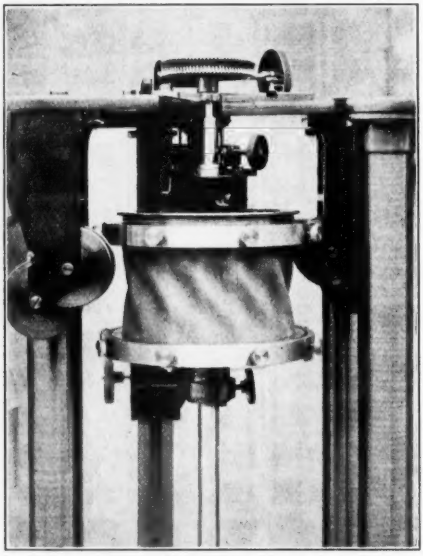

FIG. 6.

critical stage the rate of deformation suddenly becomes large, and the movement of the shell wall continues unlimitedly to increase with time, despite the fact that there is no increment in the loading. At this stage the corrugations do not change their forms or travel about on the rubber surface. Such a state as in which the hysteresis of the rubber is evidenced, or in which the linearity of the stress-strain relation ceases to hold, was not reached in our experiments, for the reason that with the removal of the loads the cylinder quickly recovered from the twisted state. Another reason for what has just been stated is that, in the buckled state, the stresses in the rubber cylinder wall are far below those stresses that exist at the limit of the almost straight part of the curve representing the stress-strain relation in the diagram, illustrating an experiment that I made in order to ascertain the Young's modulus of rubber.

Six different hollow rubber cylinders were used in my experiments, their dimensions being as below.—

No. of Model.	I	II	III	IV	V	VI
Length (cm.) ...	5.2	5.3	10.1	10.1	10.2	20.1
Thickness (mm.) ...	0.6	1.7	1.7	2.4	2.8	2.8

An example of general view of the corrugations as they form after the critical state of the buckling is reached is shown in Fig. 6. The photograph corresponds with the case $2b=52$ mm., $h=0.6$ mm.

From the measurement, it can easily be seen that the directions of the corrugations are inclined to the axis of the cylinder. The shorter the cylinder the greater is the inclination of these wrinkles. It may also be seen from the result that the wrinkles increase in number as the length of the cylinder diminishes. These phenomena are just what I expect from my mathematical theory of buckling. The critical moment of load, the number of wrinkles or corrugations, and the inclinations of these corrugations are shown in the following table:—

TABLE V.

Model.	2a (cm.)	2b (cm.)	h (mm.)	Critical Moment (gr.-cm.) Calc.	Expt.	No. of Lobes Calc.	Expt.	Incl. ($\theta°$) (Expt.)
I	10.0	5.2	0.6	480	600	4	8	$37° \sim 40°$
II	,,	5.3	1.7	9,940	5,250	4	6	$38°$
III	,,	10.1	1.7	2,850	4,250	2	5	$23°$
IV	,,	10.1	2.4	8,040	13,000	2	4	$25°$
V	,,	10.2	2.8	12,550	20,000	2	4	$30°$
VI	,,	20.1	2.8	3,750	13,000	$1 \sim 2$	4	—

From this table it will be seen that the critical twisting moments obtained from calculation conform with those obtained from experiment to a certain extent. For a relatively long cylinder the conformity is not so satisfactory, the values of the critical twisting moments obtained experimentally being sometimes two or three times that derived mathematically. It may be criticised that the boundary conditions in the two classes of investigation are not identical. It is true that boundary conditions other than the radial components are not specified in the calculation. But inasmuch as the question whether the boundary may or may not be clamped does not affect the case of a long cylinder, differences in the end conditions, if any, are obviously not the cause of the difference in the twisting moments. Furthermore, I made no allowance for the axial sliding of the cylinder ends. It will, again, be found that the number of lobes in the experiment is greater than that demanded by theory, although the general tendency of these corrugations to increase with the shortening of the cylinder is the same in both cases. This last fact seems to be related to the nature of the critical torque already referred to. There are good reasons for these partial disagreements, which I will fully explain in the next chapter. At any rate, this much I can say here, and that is, that in both theory and in experiment, the buckling loads and the corresponding corrugations in the cylinder wall tend to yield the same results.

IV. Notes on the Experimental Result

In the course of my experiments, generally speaking, I observed no corrugations whose wave length was a fraction of the wave length of the other corrugations on the cylinder; consequently I observed no such corrugations of fractional wave length to travel across the surface of the cylinder. These deformations of the cylinder seemed to consist of nothing but groups of uniform corrugations, all of the same wave lengths. Sometimes in these groups, corrugations with wave lengths of the order as demanded by mathematical theory seemed to predominate. At other times the number of corrugations exceeded that required by theory. This anomaly may partly be due to a certain property inherent in the cylinder and susceptible to action during the initial stages of the buckling under the application of force, and partly due to the fact that corruga-

tions of different modes are produced by the effect of the presence of corrugations of fractional wave lengths in a certain part or parts of the cylinder surface.

The second probable cause will first be explained. Although the buckling of shell occurs when the value of S_0b^2/D is a minimum, as seen in Figs. 1, 2 and 3, the corrugations of various modes that existed at the time of critical stability assume deeper hollows, owing to the general tendency of the cylinder to buckle, so that this fact alone is sufficient to show that the discrepancy in the number of corrugations in the cylinder as caused experimentally from that required by theory is not very surprising. The simplest indication of the co-existence of deformations of different modes is in the fact that, even with a very long cylinder, the main corrugations when in the buckled condition always include certain deformed corrugations, as well as those of hyperboloid shape. In the case of a short cylinder these deformations may be due to the effect of boundary conditions of the cylinder ends; but in the case of a long cylinder, this can only be explained by the co-existence of different modes of corrugations.

The theoretical meaning of the buckling of the cylinder may be a problem relating to the initial stability of the vibratory motion at the time when there are no wrinkles on the cylinder; and even should the initial stability, say, of a certain mode of vibration, vanish, and the deformation become large, the cylinder may enter another stable state, so that we have to deal here with a different problem. This character will be seen in the experiment with a short cylinder.

It may sometimes happen that while the stability of a deformation of large amplitude is being maintained, the initial stability of a different mode of vibration will disappear, and the latter mode may become permanently unstable. We may thus conclude that the last mentioned mode of unstable deformation is the state of elastic buckling, and this is the most important mode, whereas the former mode, which becomes unstable with the smallest load, is nothing more than a preliminary manifestation of instability. While, therefore, initial instability means that the original state of the body cannot be maintained, it does not mean that the deformation will become large. From these considerations it can clearly be seen that the result of experiment may to a certain extent differ from that required by mathematical theory.

V. Concluding Remarks

Although the present example is of some idealised kind, yet we may say that such a case becomes an important guidance for the confirmation of the behaviour of a fuselage under torsion. The result tells the fact that, when the length between two adjacent transverse frames of a fuselage is comparable to its diameter, the condition of buckling is practically the same as what it would be when its length is very long. Again, it may be seen from the comparison of mathematical theory and model experiment, that the critical shearing force, as may be derived by some mathematical method, is far below that of the actual case of the fuselage.

It is an important fact that, in the buckling of one mode of deformation, corrugations of other modes of buckling deformation are also developed. But either of these buckling modes is not developed unlimitedly, so that the problem of buckling is not so detrimental to the structural strength of the fuselage. Thus, it is probable that the thickness of the fuselage of the present day may be more decreased with safety so far as its torsional stability is concerned.

In conclusion, my thanks are due to Mr. K. Kubo, who assisted me throughout the calculation and the experiment.

THE HYDRODYNAMICS OF MARINE AIRCRAFT

BY

J. H. LOWER

(Lecture delivered before the Coventry Branch, abbreviated)

In considering the design of marine aircraft, viz., flying boats and seaplanes, an entirely separate and additional subject is brought in for investigation, and upon which there would appear to be much reserve as to definite formulations and data, etc. This subject, which I prefer to entitle "Hydrodynamics," can become, besides interesting and absorbing, certainly most deep in its complexity, and it is realised only too well by those actually engaged in such investigations, the more that time passes and experience is gained.

The apparent dearth of information relating to this subject may be due to:—

(1) The proportion of marine aircraft constructed being relatively small compared with the number of landplanes; or

(2) The means by which information is obtainable being limited.

Perhaps it would be nearer the truth to assert that both these reasons contribute.

The firm of Short Brothers, with whom I have the honour of being associated, can at least claim to be in the foreground with respect to their experience in the design and construction of marine aircraft, and the gaining of this position has been assisted in no small measure by the experimental work carried out at their tank, which was constructed in 1924.

Development and Description of Flying Boats and Seaplanes

The early seaplanes were merely converted landplanes, and with floats or pontoons of a rather crude shape no attempt was made to meet the requirements necessary for operating from the sea. Usually these machines had a poor performance and were generally unsatisfactory, which probably, to a certain extent, retarded their development.

Advancement has undoubtedly been made in seaplane design, due to the competitions held for the Schneider Trophy, since the extensive researches carried out in connection with aircraft for this purpose have taught us a great deal regarding float forms, and the general behaviour of floats under these extremely severe conditions, with the result that modern floats are largely modelled upon the results of such research.

The flying boat, although developed slowly along more conventional lines, has been steadily improved upon in recent years, and it can be confidently stated that it will take its place in the front rank of the larger types of aircraft of the future. A large amount of investigation work has yet to be done, and when more systematic research is carried out, as has been done in the past for landplanes, then can we expect even more rapid improvement in design.

Regarding the two types of marine aircraft, although perhaps it is difficult to draw a line of demarcation in some respects, yet from many points of view they are essentially different.

For Service aircraft, the seaplane is generally in favour if a single engine is fitted, but for multi-engined machines boats are invariably employed, and consequently the seaplane rarely exceeds a weight of about 9,000 lbs.

This line of demarcation, however, is not so clearly defined in the case of civil aircraft, as many successful seaplanes have been built exceeding this figure, a notable example being the Short " Valetta," a twin-float seaplane whose all-up weight is 23,500 lbs., and which is powered with three " Jupiter " XI.F. engines.

This aircraft was built to obtain a direct comparison with the " Calcutta " flying boat, the two machines being almost identical as regards total all-up weight and engine power. The comparative tests seem to point to the fact that the water performance of the seaplane was superior to that of the boat in sheltered waters, but in seas of about 2 ft. or over, the latter was definitely more seaworthy.

The air performance was also favourable to the seaplane, but since in this case it was a monoplane, whereas the boat was of the biplane type, the aerodynamic " cleanliness " thus possible probably contributed largely to its superior performance.

The greater proportion of landplanes are readily convertible into seaplanes by the substitution of a float undercarriage for the usual form of land chassis, and this is leading to much co-operation between Messrs. Short Brothers and other aircraft constructors both in this country and abroad. It is interesting to note that just recently we have fitted floats to a De Havilland " Fox-Moth " machine, and although only powered with a " Gypsy-Major " engine of 130 h.p., the take-off being as good at an all-up weight of 2,100 lbs. as a De H. 60 " Moth " seaplane with floats—designed about three years ago—is at a weight of 1,800 lbs. This shows an advance in hydrodynamic efficiency which is not always apparent by a casual glance at float shapes.

Regarding the various types of seaplanes and flying boats in use to-day, it is perhaps unnecessary to enumerate them, as they are generally well known. It is interesting to note, however, in connection with seaplanes, that most countries adhere to the twin-float type, and only in the United States is the single-float pattern adopted to any extent.

The results of tests would appear to demonstrate that the single-float arrangement has definite advantages, since its hydrodynamic efficiency is better; it possesses greater longitudinal stability; is more efficient aerodynamically, and lends itself for the attachment of an amphibian undercarriage.

As in the case of the flying boat, static transverse stability has to be provided, and this is obtained by the fitting of wing floats, the weight of which is probably amply compensated for by the proportionate decrease in weight of a single float compared to twin floats having the same buoyancy.

Regarding flying boats, various methods are adopted to obtain the requisite lateral stability on the water. In England we usually resort to floats fitted well out from the centre line of the machine, and termed wing-tip floats, these being suspended by a suitable arrangement of struts from the lower plane. The Dornier Company in Germany favour the attachment of stub planes, whilst the Rohrbach machines usually have much larger floats attached close in to the sides of the main hull. A further arrangement is adopted in Italy, where many flying boats are of the twin-hull type, in which case the stability considerations as for a twin-float seaplane, exist.

No doubt these varied types have their respective uses, but in any case it is safe to express an opinion that the successful design of either flying boat hulls or seaplane floats can only be accomplished by systematic experimental and research work carried out on a tank, investigating the many factors entering into the specific requirements for the successful operation of the machine under consideration.

The Need for Model Tests

Firstly, the taking-off action of a seaplane or flying boat is essentially different from that of a normal landplane. Until a speed of approximately 60 per cent. of that at which the machine becomes air borne is reached, the water

forces acting on the hull or floats predominate, and it would appear that the pilot has little, if any, fore and aft control. It will be evident, then, that the behaviour over this speed range is important for the safety of the machine, and, in addition, as the take-off speed is approached, manipulation of the controls by the pilot must not act adversely upon the stability or hydro-planing characteristics.

All flying boats and seaplanes have characteristics peculiar to themselves, much depending upon the type of machine and the relative position of the centre of gravity and propeller thrust axis, and experience has shown that each machine is advantageously investigated on its own merits.

It is necessary that, for an efficient take-off, the value of the water resistance of the hull or floats must be as low as possible, for the available thrust from the airscrew has to overcome the combined water and air drags, with a surplus for producing acceleration on the machine.

Also, since the hull or floats are necessarily attached to the machine at some fixed position and angle relative to the planes, it is important to know the running angle at any speed, so that the planes are used efficiently during the take-off in reducing the actual water-borne load.

Seaworthiness, and the ability to taxi in rough water without excessive spray damaging the airscrews, the type of wave formation, and whether water will be thrown over the lower planes or tail unit, etc., are among many other points which clearly indicate the necessity for model tests on a tank, not forgetting that to facilitate progress new channels have to be explored with a view to obtaining additional data which will prove of use to those engaged in the design of the machines.

Description of a Tank and its Apparatus

Two tanks which I have had the privilege of visiting, viz., at the National Physical Laboratory, Teddington, and Messrs. Vickers, Ltd., St. Albans, although primarily erected for the carrying out of model ship experiments, have contributed to the development of float and hull shapes. At the present time the apparatus for a new tank, erected for the Air Ministry at Farnborough, is undergoing final tests, and when this is in formal operation further much-needed researches should be accelerated.

When Messrs. Short Brothers commenced to specialise in the design of marine aircraft, the importance of model tests was fully realised if any systematic progress was to be made, and hence, early in 1924, a tank, although small compared to others, was put under construction.*

Recently we have erected an alternative arrangement for supporting a model during normal running tests which dispenses with the swinging and vertical sliding frames, and instead, two long, light wires, hanging vertically, support the balanced model from its representative C.G. position. Wires also connect the model to the resistance-recording torsion rod lever, replacing the towing rod.

Counterbalance weights are used to give the correct model displacement for any desired condition.

This system, which, as far as I am aware, was first adopted at Messrs. Vickers' tank at St. Albans, offers many advantages for particular types of tests, since any possible effects of moving masses of apparatus upon the vertical or pitching motions of the model are greatly minimised.

At the far end of the tank is erected an apparatus for producing waves, and this assists in the carrying out of tests to determine the behaviour of hulls or floats when run through rough water.

* The author here inserted a detailed description of Messrs. Short Bros. tank at Rochester, along similar lines to that previously published (1931 Journal).

Assumptions Used for Model Testing

The basic assumptions used in predicting results from models for full-size hulls and floats are essentially those developed by Froude during his experiments with ship forms and their resistances.

The relationship is usually expressed by the following equation:—

$$R = l^2 V^3 \rho \phi \{ (\nu/lV), (gl/V^2) \}$$

which represents that the resistance of a form partially submerged and moving through a fluid so as to produce a wave formation depends upon the linear

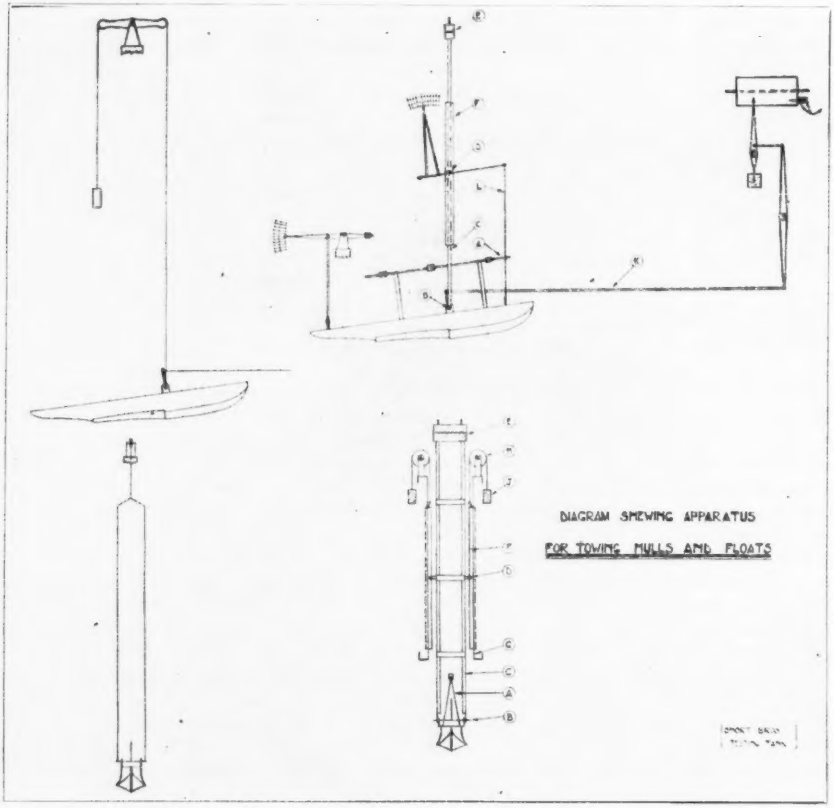

FIG. 1.

dimensions and velocity of the model, the density and viscosity of the fluid, and the force due to gravity.

The term Vl/ν, known as Reynolds number, in which is the ratio between the viscosity and density of the fluid, or kinematic viscosity μ/ρ, is neglected, thus assuming that the resistance is entirely that producing waves, eliminating the correction due to skin friction. This is an obvious error, but since the actual wetted surface at any speed would be difficult to obtain, and also that as the result thereby is to predict a larger value for the full-scale resistance, the

assumption would appear at least pardonable when the same fluid is considered for both model and full scale.

Thus, arranging that the ratio V^2/l shall be the same for both model and full size, it will be seen that

$$V_m/V = \sqrt{(l_m/l)} \quad \text{and} \quad R_m/R = (l_m/l)^3$$

where V_m l_m R_m and V, l, R refer to velocity, linear dimensions, and resistance respectively, of the model and its parent form.

V_m and V are known as "corresponding" speeds, and thus, if the model whose resistance is R_m at a velocity V_m, is of scale $1/x$, then the predicted full-scale resistance at speed $V_m\sqrt{x}$ will be $R_m x^3$.

At these speeds also, the running angle is assumed to be the same for both model and full size, whilst moments will be proportional to x^4.

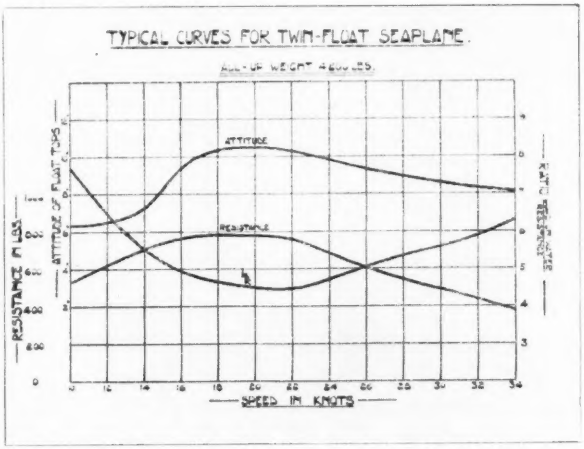

FIG. 2.

The conditions under which model tests are conducted are not absolutely identical with those under which the actual aircraft operates. The effect of the aerodynamic drag of the superstructure is normally not allowed for, whilst with the model, the towing force is equal to the resistance, whereas in full size the airscrew thrust is in excess of the combined air and water resistances, to produce acceleration, and this probably causes a nose-diving moment. Several discrepancies such as these exist, but experience has shown that in the development of all normal types of machines they have but small bearing upon the model results, which have proved to be reliable in their purpose of predicting full-scale characteristics. As stated previously, all types of machines call for their particular requirements to be investigated separately, and in so doing, the advisability in some cases of allowing for any normally neglected factors is duly considered.

*Typical Tests Carried Out, and Results**

In order that the take-off is not delayed, it is essential that floats and hulls which angle forward at higher speeds should be capable of being trimmed aft as soon as a permissible flying speed is attained, enabling the machine to become air-borne.

* Here followed a description of normal tests for resistance and running angle, with particulars of typical results obtained for up-to-date float and hull forms.

Hulls which reach their maximum attitude at the latter end of the run are usually not as easily trimmed aft, and this characteristic will be dealt with separately.

Ability to Trim at High Speeds

At any chosen constant speed on the tank, up or down loads are applied at the tail plane as was previously described, and the results are best shown by graphically plotting the moment and corresponding angle and resistance. These curves are known as " Moment-Attitude-Resistance " or " Cross " curves, and from them several interesting features are obtained.

In the case of seaplane floats, it is usual for a range of approximately 2° or 3° fore and aft of the natural running angle to be easily reached, but beyond this the moment curve becomes steeper. The resistance usually decreases as

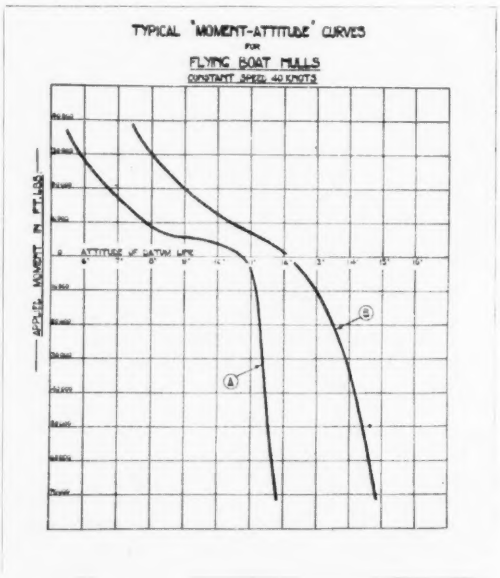

FIG. 3.

the floats are trimmed forward, reaching a minimum value at a position corresponding approximately to where the slope of the moment curve changes. This is a desirable characteristic, for such offsets the possibility of the pilot being able to trim forward sufficiently to cause the floats to submerge by the bows. Similarly, when trimmed aft, the resistance and moment values increase, preventing any undesirable occurrence consequent upon reaching a stalled position.

In practice, it happens that some machines appear to run at an angle corresponding to that of minimum resistance, whilst others show increased acceleration if trimmed forward slightly after hydroplaning has commenced. This would indicate the effect, on running angle, of the moments acting upon the machine by virtue of the aerodynamic resistance of the superstructure, and the excess airscrew thrust—as was mentioned earlier.

Many flying boat hulls have "Moment-Attitude-Resistance" curves somewhat similar to those for floats, except that the ability to trim aft is greatly reduced. This was at one time considered an advantage, particularly with that class of hull which gradually increased its running angle during the entire take-off run; a machine having this type of hull was often referred to as having an "automatic" take-off, *i.e.*, it was but little affected by the operation of the controls.

Recent experience, however, has shown that, particularly for rough water operation, a hull which can be easily trimmed fore and aft within reasonable limits is to be preferred, and consequently some of the latest types have moment curves of the float type as regards ability in being trimmed aft. The curves shown give comparative moments against angle for hulls of the two types mentioned.

The size of wing-tip floats required to give requisite transverse stability to flying boats, and single-float seaplanes, has been a controversial matter for a considerable period. Much depends upon the type and size of machine, the shape of wing float adopted, and the height of the floats above the water, which affects the permissible angle of heel.

Recently, however, an official requirement has been laid down in the case of civil machines, which states that the buoyancy of each float shall be not less than:—

$$(kW/S)\,(h+\sqrt[3]{W})\,\sin\theta \text{ lbs.}$$

where W is the all-up weight of the aircraft in lbs.,
h is the negative metacentric height in ft. of the main hull or float,
θ is the angle of heel at which one wing float becomes totally submerged,
k is a coefficient having a value between .75 and 1.0 depending upon the weight of machine,
S is the distance of the floats from the centre line of machine.

A simpler formula which we have found from experience to give satisfactory size of wing-tip floats for most types of both civil and Service machines is:—

$$\Delta = WG\sin\theta/S$$

where Δ is the required displacement in lbs,
W, θ, and S are as just mentioned,
and $G = K\sqrt[3]{W}$.

The value of K depends on the type of machine, and an average value may be taken as 1.5.

Dynamic Stability

The question of stability of hulls and floats during the take-off is an extremely complicated one, and difficult to analyse. Longitudinal instability at high speeds, or in other words "porpoising," seems to depend upon various factors among which are:—

(*a*) The distance between the steps on a hull.
(*b*) The ratio of forebody to afterbody lengths.
(*c*) The shape of the transverse underwater sections.
(*d*) The position of the C.G. of the aircraft.
(*e*) The all-up weight of the machine and beam of the hull.

Referring to the last item, it has been found that for reasonable efficiency the maximum beam of a hull should be about $.36\sqrt[3]{W}$, where W is the normal designed weight of the machine. For about 10 per cent. overload the resistance is approximately proportional to the all-up weight, *i.e.*, the efficiency remains about the same, whereas above this overload the beam is too small—causing a rapid increase in resistance.

Cases have been known where, with normal load, the hull or floats have been steady, but when overloaded longitudinal instability has developed.

The phenomena of porpoising has been investigated along various channels for several years, but no concrete satisfactory reasoning has so far been found to account for this peculiar occurrence.

Some machines take-off and alight very steadily, whilst others develop vertical or pitching oscillations—or a combination of both—sometimes to a dangerous degree.

A serious attempt has been made, both at Messrs. Short Brothers and at the R.A.E. Farnborough, to solve the problem theoretically, but since the actual under-water shapes of hulls and floats have not yet been determined mathematically, it will no doubt be appreciated that a most complicated task is being attacked. The investigations have first commenced with the study of a flat plate when assumed run at some fixed angle to the water line. The plate is then subjected to vertical and rotational displacements, and expressions derived endeavouring to obtain the resultant motion.

The validity of some of the assumptions made is certainly questionable, but perhaps by the time we have progressed sufficiently to compare the simple flat plate to an unknown form such as the planing bottom of a flying boat hull, it may be possible to lay down definite rules for the avoidance of the trouble.

Tests with a dynamically true-to-scale model, *i.e.*, representing correctly the full-size mass and moment of inertia, and complete with planes, nacelles, tail unit, etc., would certainly serve a useful purpose in predicting the actual behaviour of a machine during the take-off run, but such a model would be costly, and hardly suitable for the carrying out of the numerous alterations that are usually necessary when developing the shape of hull or floats for a new machine.

An alternative theory propounded is that, in lieu of a dynamically true model, the tests on a tank should always be conducted with the ratio of model mass to inertia the same as for the full-size aircraft. This is more easily accomplished and has been tried, but so far we have not found any definite justification.

It would appear reasonable to assume that a model which does not porpoise predicts definite steadiness for the full-size machine which it represents, although many times a model will porpoise without such action developing in practice. This is no doubt due to the damping effect of the aerodynamic forces on the superstructure of the aircraft.

Usually, therefore, we consider that a hull or floats will be satisfactory as regards dynamic stability provided the model oscillations, if any, are of a slow period type, since, under conditions of acceleration as are experienced in the actual take-off, such oscillations would be greatly restricted in their development.

We do know, however, that although our methods may have been on a so-called " trial and error " basis, we have definitely succeeded in modifying a model of a hull which porpoised violently in full size, and when such modifications were incorporated on the machine the trouble was shown to have been entirely eliminated.

The hydrodynamics of marine aircraft covers such a vast field that further surveying can always be advantageously attempted, and periodically we so endeavour at our tank. The investigations are too numerous to mention here, so I propose to just briefly refer to two cases.

(1) *Scale Effect*

If all the factors that may be involved in the hydrodynamics of seaplane testing are taken into account, a complex mathematical expression is obtained, and, as explained previously, it is impossible to satisfy this expression simultaneously for any hull and model prototypes, so that, strictly speaking, direct dynamic similarity is never obtained. Tank technique has been developed on the fact that for all surface craft the wave-making resistance is of paramount importance, and hence, as mentioned previously, all tests are carried out

in accordance with Froude's Law of Corresponding Speeds. In ship work, viscous drag contributes largely to the total resistance, and corrections are made accordingly; but in the case of marine aircraft, such is neglected.

The scale of the model is determined by the maximum equivalent speed required, or obtainable with the tank carriage, consistent with it being of such a size that errors due to the interference of the walls of the tank may be disregarded.

Although, theoretically, dynamic similarity is impossible, experience shows that actually there is a close approximation to it, since full-scale performance can be predicted with reasonable accuracy from model results. Fulfilling only the requirement for true representation of wave formation, it is apparent that there is a " scale effect " due to viscosity, surface tension, etc.

Marked differences between model and full scale should obviously be capable of being detected to a less degree between models of different sizes. Accordingly experiments were conducted with three models of different scale, each representing the same hypothetical full-size hull.

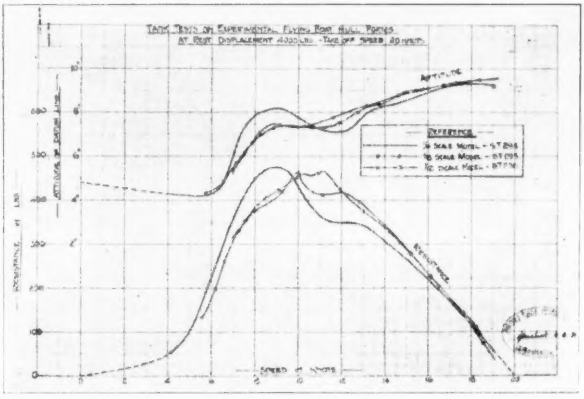

FIG. 4.

The results obtained were exceedingly interesting, since it was apparent that scale effect did exist, but the agreement, particularly at high speeds, was sufficient to indicate the reliability of the assumption that resistance was almost entirely that due to wave formation.

(2) *Pressure Distributions*

Little is known of the local pressures experienced on the planing surfaces of hulls and floats when operating on the water, particularly during take-off and alighting. Attempts have been made in the United States and in this country to measure the forces on actual machines, but no very reliable data has as yet accumulated. We endeavoured to record the pressures on the bottom of a model hull under various conditions, and to a certain degree were successful. It was possible to arrive at the form of the pressure gradient from lines of constant pressure which were plotted, but in attempting to integrate the vertical and horizontal components difficulty was experienced in arriving at a reasonable agreement with the known load on water and resistance respectively, which agreement should exist.

It was apparent that a normal hull planing surface was too complex a form upon which to commence such an investigation, hence experiments were once more attempted but with a simple flat plate. The underlying scheme was to first examine the pressure distribution over a flat plate at different angles and velocity, and then form two plates into a " Vee " shape as a first stage towards a flying boat shape.

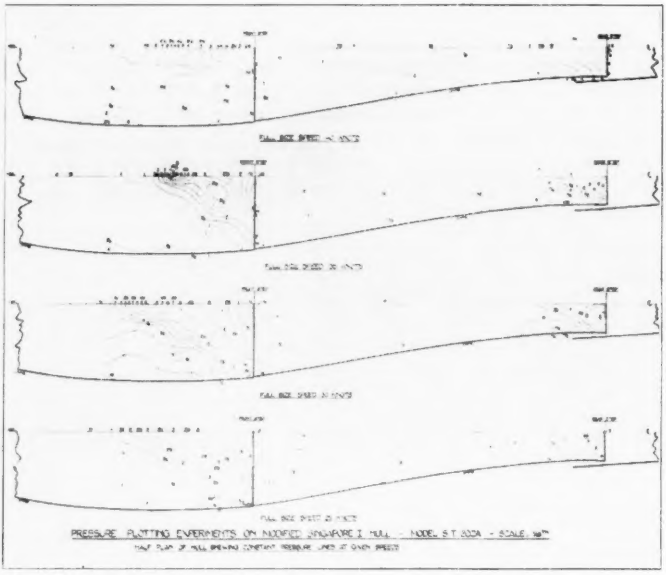

FIG. 5.

FIG. 6.

Short Kent. 4 Bristol Jupiter X.F.B.M. engines. Weight 32,000lbs. 16 passengers, 3 crew, luggage and 1½ tons of mails. Normal range 450 miles.

Curves showing transverse and longitudinal pressure distribution were obtained with the flat plate, and from these, lines of constant pressure were plotted at various speeds. The pressures were integrated, and the summations were in remarkable agreement with the measured total pressure.

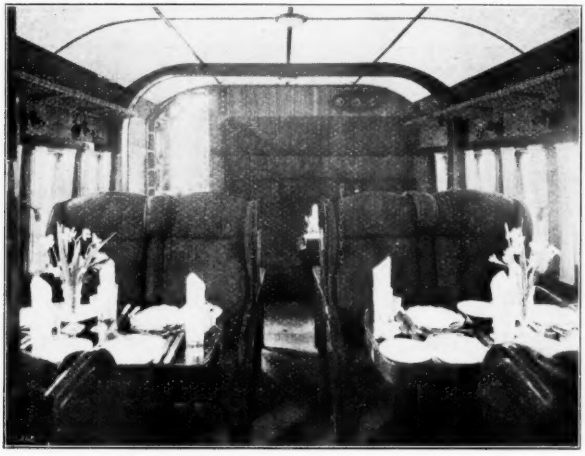

FIG. 7.
Interior of Short Kent.

The results so far are encouraging, in that our methods for measuring pressures with models would appear to be correct, and it is still hoped that the work may proceed until eventually some concrete information relating to this subject will have been obtained.

FIG. 8.
Short R.6/28. Military flying boat. Wing span 120ft. Overall length 89ft. 6in. Maximum all-up weight 70,000lbs. 6 Rolls-Royce Buzzard engines.

Researches such as these can only be thoroughly exhausted at a slow pace, and the amount of work involved and the analysing of results could form a separate topic of some length.

However, by what has been mentioned, I hope it will be appreciated that the hydrodynamics of marine aircraft forms a vast subject and one which is of vital importance.

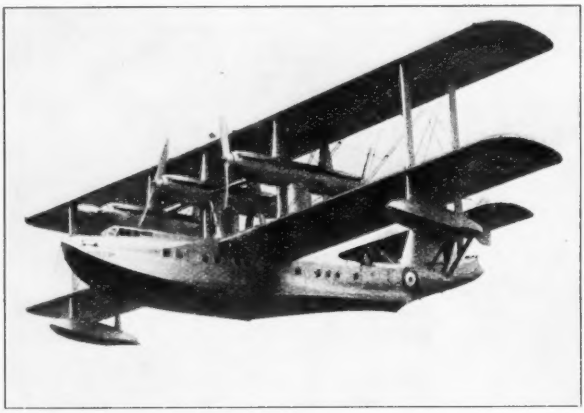

FIG. 9.
Short R.6/28 in flight.

The results which we have obtained experimentally during the past seven or eight years have materially assisted in the design of our firm's products, and before concluding it may be of interest to briefly refer to some of the machines.*

* The author then described, with the aid of lantern slides, many interesting features of the latest machines produced by Messrs. Short Bros., and expressed his thanks to Messrs. Lipscomb and Medhurst for their assistance in the preparation of the lecture.

RESUMÉ

of

COMMERCIAL INFORMATION

SPECIAL ISSUE

Regular Air Transport Companies in Europe

Returns showing
Details of Fleets in Operation as
at 31st December, 1932

Issued by the Directorate of Civil Aviation (C.A.3)
Air Ministry
March 7th, 1933
435

COUNTRY.	Total No. of Civil Aircraft on Register of Country.	REGULAR AIR TRANSPORT. Operating Company.	Total No. of Aircraft in Operation.	Total available Pay Load (Lbs.).	Average Available Pay Load per Aircraft (Lbs.).	Total H.P. of Fleet.	Average H.P. per Aircraft.	Average Available Pay Load (Lbs.) Per H.P.	Total Mileage of Routes Operated 1932.	Scheduled Weekly mileage 1932.	Average Scheduled Weekly Mileage per Aircraft 1932.
GREAT BRITAIN	981	I.A.L.	29	136,622	4,711·7	44,700	1,541·4	3·0	11,263	36,941	1,274
AUSTRIA	58	O.L.A.G.... ...	10	13,368	1,336·8	5,425	542·5	2·5	2,297	14,104	1,410
BELGIUM (Inc. Congo) ...	159	S.A.B.E.N.A. ...	39	84,004	2,154·0	25,680	658·4	3·3	2,987	35,613	913
CZECHOSLOVAKIA	138	C.L.S.	13	24,460	1,882·3	7,680	590·7	3·6	1,008	9,280	714
		C.S.A.	14	22,220	1,587·1	6,150	439·3	2·9	836	12,708	908
		TOTAL ...	27	46,680	1,747·6	13,830	512·2	3·4	1,844	21,988	814
DENMARK	12	D.D.L.	5	7,700	1,540·0	1,865	373·0	2·4	352	2,738	550
FINLAND	17	AERO O/Y ...	4	7,540	1,885·0	3,175	793·7	306	3 318	829	
FRANCE	1,600	A.U.	40	59,560	1,489·0	29,230	730·7	2·0	2,022	28,942	724
		C.I.D.N.A. ...	25	42,357	1,694·3	14,900	596·0	2·8	2,643	15,858	634
		C.G.T.A.	23	40,821	1,774·8	12,445	541·1	3·3	1,966	10,134	441
		A.O.	31	54,267	1,750·5	23,250	750·5	2·3	7,630	15,260	492
		C.G.A. (EUROPE)	82	112,088	1,366·9	43,130	538·2	2·5	5,494	32,792	400
		(S. AMERICA)	58	72,226	1,245·3	26,600	458·6	2·7	4,453	10,836	187
		TOTAL ...	259	381,319	1,472·3	149,555	581·3	2·5	24,608	113,822	439·5
GERMANY	1,031	DERULUFT ...	12	17,466	1,455·5	7,500	625·0	2·3	1,704	28,784	2,399
		D.V.	19	19,200	1,010·5	2,820	148·4	6·8	1,104	22,788	1,199
		D.L.H.	147	223,409	1,519·8	80,545	547·9	2·8	20,395	141,670	964
		TOTAL ...	178	260,075	1,461·1	90,865	510·5	2·9	23,203	193,242	1,086
GREECE	—	S.H.C.A.	4	9,176	2,294·0	3,600	900·0	2·6	460	5,520	1,380
HUNGARY	73	MALERT	6	15,045	2,507·5	4,050	675·0	3·7	917	7,938	1,323
ITALY	578*	S.A.A.L.I. ...	8	17,640	2,205·0	6,000	750·0	2·9	1,023	6,660	832
		S.A.N.A.... ...	14	32,681	2,334·4	17,000	1,214·3	1·9	2,334	20,556	1,468
		S.I.S.A.	11	18,000	1,636·3	7,900	718·2	2·3	848	10,404	946
		S.A.M.	29	46,178	1,592·3	18,875	1,650·9	2·5	3,722	30,122	1,039
		S.A.A.E.I.† ...	16	34,550	2,159·4	15,100	943·7	2·3	1,194	5,144	322
		S.A.N.A.A. ...	4	8,800	2,200·0	3,360	840·0	2·6	830	3,980	995
		TOTAL ...	82	157,849	1,925·0	68,235	832·1	2·3	9,951	76,866	937
JUGO-SLAVIA	9	AEROPUT... ...	9	7,536	837·3	3,625	402·8	2·1	795	4,476	497
NETHERLANDS	61	K.L.M.	35	84,839	2,425·8	30,515	871·9	2·8	9,899	41,186	1,176
		K.N.I.L.M. ...	8	20,370	2,547·0	6,630	828·7	3·1	1,617	4,816	802
		TOTAL ...	43	105,263	2,448·0	37,145	863·9	2·8	11,516	46,002	1,070
POLAND	125	LOT	28	42,420	1,515·0	12,220	436·4	3·5	3,000	22,778	814
ROUMANIA	—	L.A.R.E.S. ...	8	9,220	1,152·5	3,210	401·2	2·9	702	6,534	817
SPAIN	82	L.A.P.E.... ...	9	18,733	2,081·4	7,540	837·7	2·5	571	7,994	888
SWEDEN...	22	A.B.A.	7	12,473	1,781·7	5,975	853·6	2·1	1,040	11,390	1,627
SWITZERLAND	79	SWISSAIR... ...	12	21,325	1,777·1	7,945	661·7	2·7	2,523	17,908	1,492
—		ALPAR	3	2,858	952·6	590	196·6	4·8	265	3,564	1,188
		TOTAL ...	15	24,183	1,612·2	8,535	568·7	2·8	2,788	21,472	1,432

* With reference to the corresponding figure given in the Return as at 31st December, 1931, for "859" read "659."

† Details as at 31.12.1931.

COMPANY.	Flying Personnel. Pilots.	Engineers.	W.T. Operators.	Total.	Aircraft. No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	Engines. No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						GREAT BRITAIN.									
IMPERIAL AIRWAYS, LTD., Airways Terminus, Victoria Station, (Continental Departures), London, S.W. 1.	35	12	19	66	2	Armstrong Whitworth "Argosy I.A"	18,500	4,050	8,100	95	3	Armstrong Siddeley "Jaguar VI.A"	420	1,260	2,520
					3	Armstrong Whitworth "Argosy II"	19,200	4,500	13,500	95	3	Armstrong Siddeley "Jaguar VI.AA"	420	1,260	3,780
					2	Handley Page "W.10"	13,800	3,140	6,280	87	2	Napier "Lion"	440	880	1,760
					4	Handley Page "Hannibal" ...	29,500	7,000	28,000	105	4	Bristol "Jupiter XI.F"	490	1,960	7,840
					4	Handley Page "Heracles" ...	30,000	6,625	26,500	105	4	Bristol "Jupiter X F.B.M." ...	555	2,220	8,880
					5	De Havilland "66"	15,600	3,075	15,375	95	3	Bristol "Jupiter VI"	425	1,275	6,375
					4	Short "Calcutta" (S)	22,500	4,198	16,792	90	3	Bristol "Jupiter XI.F."	485	1,455	5,820
					3	Short "Scipio" (S)	32,000	6,270	18,810	105	4	Bristol "Jupiter X F.B.M." ...	555	2,220	6,660
					1	Westland "Wessex"	6,000	900	900	95	3	Armstrong Siddeley "Genet Major"	140	420	420
					1	Avro X	10,225	2,365	2,365	95	3	Armstrong Siddeley "Lynx IV.C"	215	645	645
(I.A.L.)					29				136,622						44,700
						AUSTRIA.									
ÖSTERREICHISCHE LUFTVERKEHRS A.G., Weihburggasse 9, ... Vienna 1.	10	3	5	18	1	Junkers G.31	18,760	2,900	2,900	105	3	Gnome et Rhone "Jupiter" ...	480	1,440	1,440
					2	Junkers G.24	14,326	2,294	4,588	93	3	Junkers "L.5"	310	930	1,860
					6	Junkers F.13	4,400	880	5,280	95	1	Junkers "L.5"	310	310	1,860
					1	Junkers A.20	3,500	600	600	105	1	Junkers "L.2"	265	265	265
(O.L.A.G.) ...					10				13,368						5,425
						BELGIUM.									
SOCIÉTÉ ANONYME BELGE D'EXPLOITATION DE LA NAVIGATION AERIENNE (Europe)	14	6	7	27	22	Fokker F VII b.3.m.	11,000	2,205	48,510	93	3	Gnome et Rhone "Titan" ...	230	690	15,180
					4	Westland "Wessex IV"	6,000	1,055	4,220	95	3	Armstrong Siddeley "Genet Major"	140	420	1,680
					26				52,730						16,860
13, Rue Brederode, Brussels (Congo)	5	6	—	11	6	Fokker F VII b.3.m.	11,000	2,205	13,230	93	3	Gnome et Rhone "Titan" ...	230	690	4,140
					5	Handley Page "W.8.F."... ...	12,000	3,150	15,750	93	1	Rolls Royce "Eagle IX" ...	360	840	4,200
											2	Armstrong Siddeley "Puma" ...	240		
					2	D.H. 50	4,200	1,147	2,294	95	1	Armstrong Siddeley "Puma" ...	240	240	480
(SABENA)					13				31,274						8,820
TOTAL	19	12	7	38	39				84,004						25,680

NOTE :—(S) = Seaplane. (AMP) = Amphibian.

COMPANY.	Flying Personnel.				Aircraft.						Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						CZECHOSLOVAKIA.									
CESKOSLOVENSKE STATNI AEROLINIE, Vaclavske Namesti 72, Prague 11.	8	—	4	12	7	Aero A.35	4,070	1,100	7,700	102	1	Walter "Castor"	240	240	1,680
					5	Fokker Avia F.VII	11,000	2,200	11,000	93	3	Walter "Castor"	240	720	3,600
					1	Caproni Ca. 97	5,500	1,320	1,320	105	3	Walter "Mars"	145	435	435
					1	Letov. S.32...	16,750	2,200	2,200	93	3	Walter "Mars"	145	435	435
(C.S.A.)					14				22,220						6,150
CESKOSLOVENSKA LETECKA SPOLECNOST Vodickova 36, Prague 11.	6	6†	—	12	3	Fokker VII b.3.m.	11,000	2,205	6,615	93	3	Skoda Wright "Whirlwind" ...	210	630	1,890
					2	Fokker VII b.3.m.	11,000	2,205	4,410	95	3	Walter "Castor"	240	720	1,440
					3	Fokker VII b.3.m.	11,000	2,205	6,615	95	3	Skoda "D.14"	250	750	2,250
					2	Fokker VII a	7,935	1,760	3,520	92	1	Walter "Jupiter IV"	420	420	840
					3	Avia B.H.25	6,336	1,100	3,300	90	1	Walter "Jupiter IV"	420	420	1,260
(C.L.S.)					13				24,460						7,680
						DENMARK.									
DET DANSKE LUFTFARTSELSKAB A.S. Kastrup Airport, Copenhagen (D.D.L.)	3	4†	—	7	4	Fokker VII A	7,935	1,760	7,040	92	1	Bristol "Jupiter VI"	440	440	1,760
					1	Desoutter Mk. 11	2,000	660	660	105	1	De Havilland "Gipsy 111" ...	105	105	105
					5				7,700						1,865
						FINLAND.									
AÉRO O/Y. Kruunnuvuorenkatu 3, Helsingfors.	4	5	2	11	1	Junkers JU.52/3m (S)	19,830	3,740	3,740	115	3	Pratt & Whitney "Hornet" ...	525	1,575	1,575
					1	Junkers G.24 (S)	16,750	2,200	2,200	93	3	Junkers "L.5"	320	960	960
					2	Junkers F.13 (S)	5,950	800	1,600	93	1	Junkers "L.5"	320	320	640
(AERO O/Y) ...					4				7,540						3,175

NOTE: (S) = Seaplane. (AMP) = Amphibian. † = Trained as W/T Operators.

COMPANY.	Flying Personnel.				Aircraft.						Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight. (Lbs.)	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.)	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						FRANCE.									
SOCIÉTÉ GÉNÉRALE DE TRANSPORTS AÉRIENS, 167, Rue de Silly, Billancourt.	8	—	6	14	5	Farman 170	7,040	1,700	8,500	112	1	Farman	500	500	2,500
					4	Farman 190	7,260	2,200	8,800	95	1	Gnome et Rhone "Titan" ...	230	230	920
					6	Farman 301	9,986	1,800	10,800	100	3	Salmson	230	690	4,140
					1	Farman 302	9,986	1,800	1,800	100	1	Hispano Suiza	650	650	650
					2	Farman 303	9,986	1,800	3,600	100	3	Gnome et Rhone "Titan" ...	230	690	1,380
					2	Farman 306	9,986	1,800	3,600	100	3	Lorraine "Mizar"	240	720	1,440
					1	Farman 307	9,986	1,800	1,800	100	3	Renault	250	750	750
					1	Farman 250	5,100	1,241	1,241	100	1	Gnome et Rhone "Jupiter" ...	380	380	380
					1	Farman 281	2,200	680	680	105	3	Renault	95	285	285
(S.G.T.A.)... ...					23				40,821						12,445
COMPAGNIE INTERNATIONALE DE NAVIGATION AERIENNE 22, Rue des Pyramides, Paris (Ier).	21	—	11	32	2	Wibault Penhoet 282 T.12 ...	13,030	3,000	6,000	128	3	Gnome et Rhone "Titan" "Major K.7"	350	1,050	2,100
					4	Fokker VII b 3.m...	11,000	2,205	8,820	95	3	Gnome et Rhone "Titan" "Major K.7"	350	1,050	4,200
					3	Fokker VII b 3.m...	11,000	2,205	6,615	95	3	Gnome et Rhone "Titan" ...	230	690	2,070
					6	Fokker VII a	7,935	1,760	10,560	92	1	Gnome et Rhone "Jupiter 9A"...	420	420	2,520
					2	Bernard 190	7,260	2,200	4,400	110	1	Gnome et Rhone "Jupiter 9A"...	420	420	840
					7	Potez 29	2,574	726	5,082	115	1	Gnome et Rhone "Jupiter 9A"...	420	420	2,940
					1	Farman 190	3,968	880	880	95	1	Gnome et Rhone "Titan" ...	230	230	230
(C.I.D.N.A.) ...					25				42,357						14,900
COMPAGNIE AIR ORIENT, 2, Rue Marbeuf, Paris (VIII.e.)	18	18	17	53	2	Breguet 284.T	7,750	1,760	3,520	120	1	Hispano Suiza	580	580	1,160
					3	Farman 190	7,260	2,200	6,600	95	1	Gnome et Rhone "Titan" ...	240	240	720
					3	Farman 303	9,986	1,800	5,400	100	3	Gnome et Rhone "Titan" ...	240	720	2,160
					7	Fokker F.VII. b.3.m.	11,000	2,205	15,435	95	3	Gnome et Rhone "Titan" ...	240	720	5,040
					3	Potez 32	3,850	1,000	3,000	95	1	Gnome et Rhone Salmson A.B.9	230	230	690
					4	Cams 532 (S)	15,840	1,760	7,040	103	2	Hispano Suiza	580	1,160	4,640
					7	Cams 531 (S)	15,840	1,760	12,320	103	2	Hispano Suiza	580	1,160	8,120
					2	Schreck 17 (S)	2,816	476	952	90	2	Hispano Suiza	180	360	720
(A.O.)					31				54,267						23,250

NOTE: (S) = Seaplane. (AMP) = Amphibian.

COMPANY.	Flying Personnel.				Aircraft.						Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						FRANCE (*Contd.*)									
COMPAGNIE GÉNÉRALE AEROPOSTALE, 5, Avenue de Friedland, Paris (VIII.e.)	46	10	23	79	24	Latecoere 25	7,223	1,225	29,400	89	1	Renault "12.J."	450	450	10,800
					21	Latecoere 26	7,073	900	18,900	90	1	Renault "12.J."	450	450	9,450
					11	Latecoere 28	8,800	2,000	22,000	119	1	Renault	500	500	5,500
					8	Latecoere 28	8,800	2,000	16,000	119	1	Hispano Suiza	500	500	4,000
					1	De Havilland "Moth" ...	1,525	440	440	85	1	De Havilland "Gipsy I" ...	80	80	80
					2	Breguet 14	3,968	800	1,600	83	1	Renault	300	300	600
					3	Latecoere 33 (S)	16,507	1,516	4,548	102	2	Hispano Suiza	500	1,000	3,000
(*a*) Toulouse-Dakar and Marseilles-Algiers Services				(*a*)	4	Latecoere 28–3 (S)	11,044	1,500	6,000	110	1	Hispano Suiza	600	600	2,400
					2	Cams 53 (S)	13,816	1,800	3,600	102	2	Hispano Suiza	500	1,000	2,000
					2	Cams 53 (S)	13,816	1,800	3,600	102	2	Hispano Suiza	600	1,200	1,400
					1	Latham 47 (S)	3,800	800	800	110	2	Hispano Suiza	500	1,000	2,000
					1	Leo H. 24 (S)	15,960	2,200	2,200	108	2	Renault	500	1,000	1,000
					2	Loire et Olivier 198 (AMP) ...	6,930	1,500	3,000	80	1	Renault	450	450	900
					82				112,088						43,130
					20	Latecoere 25	7,223	1,225	24,500	89	1	Renault "12.J."	450	450	9,000
					21	Latecoere 26	7,073	900	18,900	90	1	Renault "12.J."	450	450	9,450
					2	Latecoere 28	8,800	2,000	4,000	119	1	Renault	500	500	1,000
					8	Latecoere 28	8,800	2,000	16,000	119	1	Hispano Suiza	500	500	4,000
(*b*) Services in South America				(*b*)	5	Potez 25	5,016	1,320	6,600	120	1	Lorraine	450	450	2,250
					1	Potez 29	2,574	726	726	115	1	Lorraine	450	450	450
					1	Loire et Olivier 198 (AMP) ...	6,930	1,500	1,500	80	1	Renault "12.J."	450	450	450
(C.G.A.)					58				72,226						26,600
COMPAGNIE AIR UNION, 9, Rue Auber, Paris (IX)	24(a) 6(S)	18	14	62	15	Breguet "280T."	7,750	1,800	27,000	120	1	Renault	500	500	7,500
					11	Loire et Olivier "H.199" ...	7,502	1,200	13,200	105	2	Renault	500	1,000	11,000
					5	Farman "190"	3,968	880	4,400	95	1	Gnome et Rhone	230	230	1,150
					1	Dewoitine	3,880	880	880	110	1	Wright "Whirlwind"	300	300	300
					8	Cams 532 (S)	15,840	1,760	14,080	103	2	Hispano Suiza	580	1,160	9,280
(A.U.)					40				59,560						29,230

NOTE. (S) = Seaplane. (AMP) = Amphibian.

COMPANY.	Flying Personnel.				Aircraft.							Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						GERMANY.									
DEUTSCHE LUFT HANSA A.G. Lindenstrasse 35, ... Berlin, S.W. 68	103	56	58	217	1	Junkers G.38	50,706	8,818	8,818	103	4	Junkers "L.88A"	800	3,200	3,200
					1	Junkers G.31	18,739	3,307	3,307	104	3	Siemens "Jupiter U"	450	1,350	1,350
					4	Junkers G.31	18,739	3,307	13,228	104	3	B.M.W. "Hornet"	450	1,350	5,400
					8	Junkers G.24	14,330	1,764	14,112	104	3	Junkers "L.5"	275	825	6,600
					2	Rohrbach Roland	16,755	2,205	4,410	100	3	Junkers "L.5"	300	900	1,800
					10	Rohrbach Roland	16,755	2,205	22,050	100	3	B.M.W. "V.A"	320	960	9,600
					20	Dornier Merkur	7,936	992	19,840	92	1	B.M.W. "6"	500	500	10,000
					11	Fokker F. II.	5,070	838	9,218	84	1	B.M.W. "5.A"	320	320	3,520
					6	Fokker F. III.	5,070	1,014	6,084	94	1	B.M.W. "5.A"	320	320	1,920
					2	Fokker F. III.	5,070	1,014	2,028	94	1	B.M.W. "4"	270	270	540
					21	Junkers F.13	4,630	772	16,212	91	1	Junkers "L.5"	275	275	5,775
					12	Junkers F.13	4,409	772	9,264	91	1	B.M.W. "4"	270	270	3,240
					7	Junkers W.33	6,614	1,896	13,272	110	1	Junkers "L.5"	300	300	2,100
					10	Focke-Wulf A.17	8,818	1,609	16,090	92	1	Jupiter "U" or Siemens "Jupiter U"	450	450	4,500
					2	Focke-Wulf A.29	9,700	2,160	4,320	96	1	B.M.W. "6"	500	500	1,000
					4	Focke-Wulf A.38	9,700	2,205	8,820	94	1	Jupiter "U" or Siemens "Jupiter U"	450	450	1,800
					7	Junkers F.24	10,141	1,411	9,877	93	1	B.M.W. "6.U"	500	500	3,500
					1	Junkers F.24	10,141	1,411	1,411	93	1	B.M.W. "7.A.U."	600	600	600
					1	Junkers F.24	11,023	1,499	1,499	93	1	Junkers "Jumo IV"	650	650	650
					6	Dornier Wal (S)	14,330	1,212	7,272	108	2	B.M.W. "6"	500	1,000	6,000
					1	Dornier Wal (S)	13,448	1,212	1,212	108	2	"Jupiter "U"	450	900	900
					1	Heinkel H.E.58 (S)	6,922	1,526	1,526	99	1	B.M.W. "Hornet"	450	450	450
					2	Junkers Ju.52	19,841	6,393	12,786	126	3	B.M.W. "Hornet"	450	1,350	2,700
					1	Junkers Ju.46 (S)	7,055	1,764	1,764	113	1	Hornet	450	450	450
					1	Junkers Ju.46	7,055	1,764	1,764	113	1	B.M.W. "Hornet"	450	450	450
					5	B.F.W. M.20	10,505	2,645	13,225	99	1	B.M.W. "6"	500	500	2,500
(D.L.H.)					147				223,409						80,545
DEUTSCHE-RUSSISCHE LUFTVERKEHRS-GESELLSCHAFT, Lindenstrasse 35, Berlin, S.W. 68 (DERULUFT)	10	11	—	21	4	Dornier Merkur	7,936	992	3,968	92	1	Junkers "B.M.W. VI"	600	600	2,400
					4	Junkers F.13	4,630	772	3,088	91	1	Junkers "L.5"	300	300	1,200
					2	Rohrbach Roland	16,755	2,205	4,410	100	3	Junkers "L.5"	300	900	1,800
					2	A.N.T. 9	13,000	3,000	6,000	125	3	Wright "Whirlwind"	350	1,050	2,100
					12				17,466						7,500
DEUTSCHE VERKEHRS-FLUG A.G. Nuremberg/Fürth Airport	15	—	—	15	13	B.F.W. "18.D"	2,640	900	11,700	75	1	Siemens "S.H.12"	120	120	1,560
					3	B.F.W. "18.D"	2,800	1,100	3,300	75	1	Walter "Mars"	140	140	420
					1	B.F.W. "24.A"	6,170	1,800	1,800	90	1	Junkers "L.5"	280	280	280
					2	F.W. Focke-Wulf "A.32" ...	5,070	1,200	2,400	87	1	Junkers "L.5"	280	280	560
(D.V.)					19				19,200						2,820

NOTE: (S)=Seaplane. (AMP)=Amphibian.

COMPANY.	Flying Personnel.				Aircraft.						Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (Lbs.) per Aircraft.	Total Available Pay Load (Lbs.).	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						GREECE.									
SOCIÉTÉ HELLÉNIQUE DES COMMUNICATIONS AERIENNES, Passage Férix, Athens. (S.H.C.A.)	8	3	5	16	4	Junkers G.24	14,326	2,294	9,176	93	3	Junkers "L.5"	300	900	3,600
						HUNGARY.									
MAGYAR LEGIFORGALMI R.T., 1 s.z. Vaci Utca, Budapest IV. (MALERT)	15	10	5	30	2	Fokker "VII A"	7,935	1,760	3,520	85	1	Gnome et Rhone "Jupiter" ...	450	450	900
					3	Fokker "VIII"	12,800	3,375	10,125	95	2	Gnome et Rhone "Jupiter" ...	450	900	2,700
					1	Fokker "XI"	5,520	1,400	1,400	103	1	Gnome et Rhone "Jupiter" ...	450	450	450
					6				15,045						4,050
						ITALY.									
SOCIETA ANONIMA NAVIGAZIONE AEREA, (S.A.N.A.) Piazza Della Meridiana, Genoa.	24	15	12	51	3	Dornier Superwal (S)	26,500	3,377	10,131	108	4	Siemens "Jupiter VIII" ...	500	2,000	6,000
					11	Dornier Wal (S)	13,270	2,050	22,550	110	2	Siemens "Jupiter VIII" ...	500	1,000	11,000
					14				32,681						17,000
SOCIETA AEREA MEDITERRANEA, 29, Via Regina Elena, Rome. (S.A.M.)	29	18	11	58	10	Savoia "S.55" (S)	13,700	2,300	23,000	101	2	Isotta Fraschini "Asso"... ...	500	1,000	10,000
					3	Savoia "S.71" (S)	9,900	2,090	6,270	120	3	Walter "Castor"	275	825	2,475
					2	Junkers "G.24"	14,326	2,294	4,588	100	2	Junkers "L.5"	300	1,100	2,200
											1	Isotta Fraschini "Asso"... ...	500		
					14	Junkers "F.13"	4,400	880	12,320	96	1	Junkers "L.5"	300	300	4,200
					29				46,178						18,875
SOCIETA ITALIANA SERVIZI AEREI, Palazzo del Lloyd, Triestino, Trieste. (S.I.S.A.)	7	7	5	19	6	Cant. 22 (S)	12,125	2,250	13,500	100	1	Isotta Fraschini "Asso"... ...	500	900	5,400
											2	Isotta Fraschini "Asso"... ...	200		
					5	Cant. 10 (S)	5,940	900	4,500	85	1	Isotta Fraschini "Asso"... ...	500	500	2,500
					11				18,000						7,900
SOCIETA ANONIMA AVIOLINEE ITALIANE, 48, Via Calabria, Rome. (S.A.A.L.I.)	5	4	4	13	5	Fokker VII.b.3.m.	11,000	2,205	11,025	93	3	Armstrong Siddeley "Lynx" ...	220	660	3,300
					3	Fokker VII.b.3.m.	11,000	2,205	6,615	95	3	Wright "Whirlwind"	300	900	2,700
					8				17,640						6,000
NORD-AFRICA AVIAZIONE S.A., Benghasi. (S.A.N.A.A.)	4	4	4	12	4	Caproni 101	11,200	2,200	8,800	102	1	Alfa Romeo "Jupiter"	420	840	3,360
											2	Alfa Romeo "Lynx"	210		
†SOCIETA ANONIMA AERO EXPRESSO ITALIANA, 86, Via Emilia, Rome. (S.A.A.E.I.)	10	7	4	21	9	Dornier Wal (S)	13,270	2,050	18,450	111	2	Siemens "Jupiter"	450	900	8,100
					7	Savoia "S.55"	13,700	2,300	16,100	101	2	Isotta Fraschini "Asso"... ...	500	1,000	7,000
					16				34,550						15,100
						JUGO-SLAVIA.									
DRUSTVO ZA VAZDUSNI SAOBRACAJ A.D., 3 Rue Briand, Belgrade. (AEROPUT)	4	8*	0	12	6	Potez "29"	2,574	726	4,356	115	1	Lorraine "Dietrich"	450	450	2,700
					1	Farman 300	9,986	1,800	1,800	100	3	Lorraine "Dietrich Mizar" ...	240	720	720
					1	De Havilland "Gipsy" Moth ...	1,750	600	600	85	1	De Havilland "Gipsy I" ...	85	85	85
					1	De Havilland "Fox" Moth ...	2,070	780	780	91	1	De Havilland "Gipsy III" ...	120	120	120
					9				7,536						3,625

† Details as at 31.12.1932 not available. Figures quoted are as at 31.12.1931.

* Trained as W.T. Operators.

NOTE: (S) = Seaplane. (AMP) = Amphibian.

† Details as at 31.12.1932 not available. Figures quoted are as at 31.12.1931.

* Trained as W.T. Operators.

NOTE: (S)=Seaplane. (AMP)=Amphibian.

COMPANY.	Flying Personnel. Pilots.	Engineers.	W.T. Operators.	Total.	Aircraft. No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	Engines. No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						NETHERLANDS.									
KONINKLIJKE LUCHTVAART MAATSCHAPPIJ VOOR NEDERLAND EN KOLONIEN, N.V., Hofweg 9, The Hague. (K.L.M.)	31	22	15	68	1	Fokker C.11	3,042	400	400	87	1	Armstrong Siddeley "Puma" ...	240	240	240
					1	Koolhoven F.K.40	4,600	1,000	1,000	105	1	Gnome et Rhone "Titan" ...	240	240	240
					1	Koolhoven F.K.43	2,900	924	924	102	1	Gnome et Rhone "Gipsy" ...	120	120	120
					1	Werkspoor Carley	8,820	2,200	2,200	99	1	Gnome et Rhone "Jupiter" ...	480	480	480
					1	Fokker F.VII	7,935	1,760	1,760	92	1	Gnome et Rhone "Jupiter" ...	420	420	420
					7	Fokker F.VIIa	7,935	1,760	12,320	85	1	Gnome et Rhone "Jupiter" ...	480	480	3,360
					1	Fokker F.VII.a	7,935	1,760	1,760	92	1	Pratt and Whitney "Wasp" ...	420	420	420
					3	Fokker F.VII.b.3.m.	11,000	2,205	6,615	100	3	Gnome et Rhone "Titan" ...	240	720	2,160
					3	Fokker F.VIII	13,224	3,022	9,066	105	2	Gnome et Rhone "Jupiter" ...	480	960	2,880
					1	Fokker F.VIII	13,224	3,022	3,022	110	2	Gnome et Rhone "Hornet" ...	575	1,150	1,150
					1	Fokker F VIII	13,224	3,022	3,022	110	2	Gnome et Rhone "Cyclone" ...	575	1,150	1,150
					1	Fokker F.IX	20,497	5,190	5,190	112	3	Gnome et Rhone "Jupiter" ...	480	1,440	1,440
					8	Fokker F.XII	16,420	3,570	28,560	115	3	Pratt and Whitney "Wasp" ...	420	1,260	10,080
					5	Fokker F.XVIII	16,640	1,800*	9,000	122	3	Pratt and Whitney "Wasp" ...	425	1,275	6,375
					35				85,839						30,515
KONINKLIJKE NEDERLANDSCH-INDISCHE LUCHTVAART MAATSCHAPPIJ, 5, N. Spiegelstraat, Amsterdam. (K.N.I.L.M.)	7†	9	—	16	4	Fokker F.VII.b.3.m.	11,000	2,205	8,820	93	3	Armstrong Siddeley "Lynx" ...	225	675	2,700
					2	Fokker F.VII.b.3.m.	11,000	2,205	4,410	93	3	Gnome et Rhone "Titan" ...	230	690	1,380
					2	Fokker F.XII	16,420	3,570	7,140	115	3	Pratt and Whitney "Wasp" ...	425	1,275	2,550
					8				20,370						6,630
						POLAND.									
POLSKIE LINJE LOTNICZE, 138, Rue Marszalkowska, Warsaw. (LOT.)	20	5	4	29	6	Fokker F.VII.l.m....	7,939	1,760	10,560	101	1	Lorraine "Dietrich"	450	450	2,700
					9	Fokker F.VII.b.3.m.	11,000	2,200	19,800	93	3	Skoda "Wright"	220	660	5,940
					12	Junkers F.13	4,400	880	10,560	96	1	Junker "L.5"	280	280	3,360
					1	P.W.S. 24	7,040	1,500	1,500	92	1	Skoda "Wright"	220	220	220
					28				42,420						12,220

* This is the pay load authorised owing to the extra fuel, spares, etc., that have to be carried on the Amsterdam-Batavia route.

† Trained as W.T. operators.

NOTE: (S)=Seaplane. (AMP)=Amphibian.

COMPANY.	Flying Personnel.				Aircraft.						Engines.				
	Pilots.	Engineers.	W.T. Operators.	Total.	No. of Aircraft Operating.	Make and Type.	All Up Weight (Lbs.).	Available Pay Load (lbs.) per Aircraft.	Total Available Pay Load (lbs.).	Cruising Speed m.p.h.	No.	Make and Type.	H.P.	Total H.P. per Aircraft.	Grand Total H.P.
						ROUMANIA.									
LIGNES AÉRIENNES EXPLOITÉES PAR L'ETAT, Department of Civil Aviation (Ministry of Commerce and Industry), Rue Biserica Amzei, No. 29, Bucarest, III. (L.A.R.E.S.)	7	6	3	16	4	Junkers F.13	4,400	880	3,520	96	1	Junkers "L.5"	300	300	1,200
					3	Avia. M.H.25	6,336	1,100	3,300	90	1	Junkers	420	420	1,260
					1	Farman F.60	12,000	2,400	2,400	90	2	Armstrong Siddeley "Jaguar" ...	375	750	750
					8				9,220						3,210
						SPAIN.									
LINEAS AEREAS POSTALE ESPANOLAS, 4, Plaza de la Lealtad, Madrid. (L.A.P.E.)	8	8	6	22	3	Fokker VII.b.3.m.	11,000	2,205	6,615	95	3	Wright "J.6"	300	900	2,700
					1	Fokker VII.b.3.m.	11,000	2,205	2,205	93	3	Armstrong Siddeley "Lynx IV"	230	690	690
					1	Ford 4.A.T.	10,130	1,225	1,225	107	3	Wright "Whirlwind"	300	900	900
					2	Junkers G.24	14,326	2,294	4,588	93	3	Junkers "L.5"	300	900	1,800
					1	Breguet 280.T	7,750	1,800	1,800	120	1	Renault (geared)	450	450	450
					1	Savoia S.55 (S)	13,700	2,300	2,300	101	2	Isotta Fraschini "Asso"	500	1,000	1,000
					9				18,733						7,540
						SWEDEN.									
AKTIEBOLAGET AEROTRANSPORT, 15, Kungsgaten, Stockholm. (A.B.A.)	8	12	2	22	1	Junkers Ju.52/32 (A) (S)	19,830	3,740	3,740	115	3	Pratt and Whitney "Hornet" ...	575	1,725	1,725
					2	Junkers F.13 (A) (S)	4,400	880	1,760	96	1	Junkers "L.5"	300	300	600
					1	Junkers W.34 (A) (S)	6,600	1,400	1,400	105	1	Pratt and Whitney "Hornet" ...	575	575	575
					2	Junkers G.24 (A) (S)	16,750	1,000	2,000	93	3	Junkers "L.5"	300	900	1,800
					1	Fokker F.XII (A)	15,987	3,573	3,573	115	3	Pratt and Whitney "Wasp" ...	425	1,275	1,275
					7				12,473						5,975
						SWITZERLAND.									
SOCIÉTÉ ANONYME SUISSE POUR LA NAVIGATION AÉRIENNE, 19, Walcheplatz, Zurich. (SWISS AIR.)	8	7	8	23	5	Fokker VII.b.3.m.	11,000	2,205	11,025	95	3	Wright "Whirlwind"	300	900	4,500
					2	Fokker VII.b.3.m.	11,000	2,205	4,410	93	3	Armstrong Siddeley "Lynx IV"	230	690	1,380
					1	Fokker VII.a	7,935	1,760	1,760	100	1	Wright "Cyclone"	575	575	575
					1	Compte A.C.4	1,760	350	350	80	1	De Havilland "Cirrus Hermes" ...	110	110	110
					2	Lockheed "Orion"	5,400	1,290	2,580	180	1	Wright "Cyclone"	575	575	1,150
					1	B.F.W.M. 18.D	2,800	1,200	1,200	93	1	Armstrong Siddeley "Lynx IV"	230	230	230
					12				21,325						7,945
SOCIÉTÉ D'AVIATION "ALPAR BERNE," Airport of Berne. (ALPAR BERN.)	4	2	—	6	1	Compte A.C.8	3,850	1,350	1,350	105	1	Lorraine "Dietrich Mizar" ...	240	240	240
					1	Compte A.C.4	1,760	350	350	81	1	De Havilland "Cirrus Hermes"	110	110	110
					1	Fokker F.XI	5,520	1,158	1,158	95	1	Lorraine "Dietrich Mizar" ...	240	240	240
					3				2,858						590

NOTE: (S) = Seaplane. (AMP) = Amphibian. (A) = Aeroplane.

ABSTRACTS AND NOTICES
FROM THE
SCIENTIFIC AND TECHNICAL PRESS

PHYSICS AND ENGINEERING SCIENCE

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(Prepared by R.T.P.)

LIST OF ABBREVIATIONS OF TITLES OF JOURNALS.

Aeron. Eng.	Aeronautical Engineering.
Airc. Eng.	Aircraft Engineering.
Ann. d. Phys.	Annalen der Physik (Germany), Annales de Physique (France).
Army Ord.	Army Ordinance.
Autom. Absts.	Automotive Abstracts.
Autom. Tech. Zeit.	Automobiltechnische Zeitschrift.
Autom. Eng.	Automobile Engineer.
Autom. Ind.	Automotive Industries.
Bell Tele.	Bell Telephone Laboratory.
Bur. Stan. J. Res.	Bureau of Standards (U.S.A.) Journal of Research.
Chem. Absts.	Chemical Abstracts.
Chem. and Ind.	Chemistry and Industry.
F.G.I.	Forschung auf dem Debiete des Ingenieurwesens.
Fuel.	Fuel in Science and Practice.
H.F. Technik.	Hochfrequenztechnik und Electroakustik.
Ind. and Eng. Chem.	Industrial and Engineering Chemistry.
J.R. Aer. Soc.	Journal of Royal Aeronautical Society.
J. Sci. Inst.	Journal of Scientific Instruments.
L'Aéron.	L'Aéronautique.
L.F.F.	Luftfahrtforschung.
N.A.C.A.	National Advisory Committee for Aeronautics (U.S.A.)
Phil. Mag.	Philosophical Magazine.
Phys. Rev.	Physical Review.
Phys. Zeit.	Physikalische Zeitschrift.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Proc. Roy. Soc.	Proceedings of Royal Society.
Pub. Sc. et Tech.	Publications Scientifiques et Techniques du Ministère de l'Air.
Rev. S.G.A.	Revue de la Societé Générale Aéronautique.
Rev. F. Aer.	Revue des Forces Aériennes.

Rev. Sci. Insts.	Review of Scientific Instruments.
Riv. Aeron.	Rivista Aeronautica.
S.A.E. Jrnl.	Society of Automotive Engineers Journal.
Sci. Am.	Scientific American.
Tech. Aeron.	La Technique Aéronautique.
Z.A.M.M.	Zeitschrift für Angewandte Mathematik und Meckanik.
Z.F.M.	Zeitschrift für Flugtechnik und Motorluftschiffahrt.
Z. Instrum.	Zeitschrift für Instrumentenkunde.
Z. Metallk.	Zeitschrift für Metallkunde.
Z.V.D.I.	Zeitschrift für Vereines Deutscher Ingenieure.

No. 26. MARCH, 1933

Aircraft Design

Mutual Interference of Airscrew and Body. (W. R. Andrews, Flight, Vol. 24, No. 44, 27/10/32, pp. 1008 f-g.) (5.11/25001 Great Britain.)

Empirical formulæ are fitted graphically to N.P.L. experimental values.
Further experimental data are required for design purposes.
Three references.

The Do.X Flying Boat. (C. Dornier, L'Aéron., No. 162, Nov., 1932, pp. 336-350.) (5.12/25002 France.)

The designer assembles information scattered over several publications and years and gives new data on wing loading and hull distortion. Comparison shows the superiority of water-cooled engines under full power demands at low air speeds even for short periods.

The 500 h.p. Jupiter is rated at 310 h.p. (62 per cent.) for taxying at low air speeds, while the 630 h.p. Curtiss Conqueror is rated at 520 h.p. (82½ per cent.).

Excellent photographs are reproduced.

Large Flying Boats. (C. Dornier, Luftacht, No. 7, July, 1932, pp. 278-285.) (5.12/25003 Germany.)

The performance of the Do.X is compared with other large craft, particularly Junkers G.38 and the Short "Calcutta," not unfavourably to the latter.

Improved performance is to be expected from the application of improvements in design and materials to any future craft of these types.

Aeroplane Design and Maintenance. (J. G. Lee, S.A.E. Jrnl., Vol. 31, No. 4, Oct., 1932, pp. 412-420.) (5.14/25004 U.S.A.)

Analyses of running costs and sources of accident are given from U.S.A. practice.

Photographs illustrate devices for increasing accessibility, which is the chief factor in reducing maintenance and justifies capital expenditure.

A discussion follows.

American Aircraft Construction. (K. H. Ruhl, Z.V.D.I., Vol. 76, No. 33, 13/8/32, pp. 807-808.) (5.14/25005 Germany.)

Modern U.S.A. commercial aircraft attain higher speeds by clean design and use of retractable carriages.

They compare favourably with older types on the basis of fuel consumption per ton mile, but have higher landing speeds and higher initial cost.

The author holds that the reduction of flying time will attract sufficient new traffic to justify the initial cost.

Buckling of Spars. (A. Teichmann, Z.F.M., Vol. 23, No. 17, 14/9/32, pp. 511-519.) (5.15/25006 Germany.)

The methods of Berry and Muller-Breslau are applied numerically and two families of curves enable values to be read off.

Two lines are drawn, along which the error may reach 3 per cent. and 5 per cent. respectively of the accurate value. A number of formulæ are collected in useful tabular form.

The method is extended to more complicated structures.

Nine references.

Apparatus for Investigating Vibration. (W. Späth, Z.V.D.I., Vol. 76, No. 14, 2/4/32, pp. 348-349.) (5.17/25007 Germany.)

The apparatus has four out-of-balance masses on shafts driven by two 3 h.p. motors. Forces up to 2000 kg. with a frequency up to 60 Hertz can be excited. Applications to ships and land vehicles are discussed briefly.

Five references.

Stresses in Monospar Bracing. (S. C. Redshaw, Flight, Vol. 24, No. 44, 27/10/32, pp. 1008a-d.) (5.25/25008 Great Britain.)

Lateral stiffness is secured by kingpost and bracing wires, the latter forming an octohedron. A numerical example is worked out.

Wing Construction. (H. J. Stieger, J.R. Aer. Soc., Vol. 36, No. 262, Oct., 1932, pp. 790-827.) (5.25/25009 Great Britain.)

Monoplane wing design is the principal subject of the paper. An analysis of aeroplane weights separates items which are controlled or influenced by the aeroplane designer from those—chiefly engine weights—which are outside his sphere.

Numerical data put the elementary account of the forces on wings largely on a numerical basis. Various types of monoplane wing construction are illustrated by perspective sketches. A sketch and photographs show details of a monospar construction favoured by the author. A somewhat similar Fokker monospar wing for a huge monoplane is also shown in a photograph.

The discussion shows that the author's ideas are to some extent controversial, but it appears to be agreed that monoplane construction is at least approaching biplane construction in a general comparison of flying qualities.

Variable Wing Aeroplanes. (Luftwacht, No. 7, July, 1932, pp. 273-276.) (5.254/25010 Germany.)

The wing surface may be varied by increasing either span or chord. The variable span aeroplane produced and flown by the Technical High School, Breslau, has about 16 per cent. increase of wing surface. It is stated that the starting run is reduced by ½. The variable span machine of Makhonine (France) is designed for a 73 per cent. increase in wing area. Test details are not available.

An aeroplane combining both methods is under construction. A small high speed wing of normal construction is supplemented by a fabric wing of variable span operated like a roller shutter.

Seven references.

Test Aeroplane with Variable Wing Surface. (W. Schmeider and G. Neumann, Z.F.M., Vol. 23, No. 17, 14/9/32, pp. 505-507.) (5.254/25011 Germany.)

A specification is given of main dimensions, power load and speed.

The surface is increased from 12.75 m^2 by 19.6 per cent. to 15.25 m^2.

The weight of the moving parts is given as 25 kg. No stress calculations are given.

A sketch and photographs show the method of increasing the surface by increasing the chord width along about two-thirds of the span.

The additional surface is added at the trailing edge and is of triangular shape. The speed ratio is 140 km/h. to 60 km/h.

(No numerical comparison with a normal aeroplane is given.)

Airscrews

Flow through an Airscrew. (H. C. H. Townend, Phil. Mag., Vol. 14, No. 92, Oct., 1932, pp. 700-712.) (5.6/25012 Great Britain.)

The method of observing the configuration of flow by the refraction of a beam of light by hot air filaments was described by the author in R. and M. No. 1349. Applications to the flow through an airscrew are described and illustrated by photographs which confirm previous observations by other methods.

The new method appears to give a greater possible precision. In particular the method of trailing threads in the stream is shown to be completely misleading in unfavourable conditions, such as the rapid change of direction near the nose of a wing.

Principle of Variable Pitch Airscrew. (H. J. Dudenhausen, Autom. Tech. Zeit., Vol. 35, No. 17, 10/9/32, pp. 420-422.) (5.64/25013 Germany.)

The advantages of variable pitch are discussed.

The design of a hub is discussed and illustrated by sectional diagrams. The pitch is automatically controlled by the reaction of springs and centrifugal force.

Autometer Variable Pitch Propeller. (Gobereau and Maujole, L'Aéronautique, No. 157, June, 1932, pp. 180-182.) (5.658/25014 France.)

The airscrew hub is loosely mounted on an extension of the crankshaft. A centrifugal governor acts through a link and changes the blade pitch by rotation about the radial axis.

Further control in flight is proposed by pumping oil into the governor weights and increasing their mass.

It is stated that promising flight tests have been carried out.

Instruments

Scientific Instruments and Aeronautics. (H. E. Wimperis, J. Sci. Inst., Vol. 9, No. 11, Nov., 1932, pp. 337-341.) (6.0/25015 Great Britain.)

Aeronautics has borrowed freely and adapted instrumental equipment from other branches of technology and has devised new instrumental combinations for its own needs without offering immediate assignable return on its borrowings.

The aeroplane furnishes a moving platform subject to high accelerations and intense vibrations and the instrument is so intimately affected thereby, both in physical principle and in mechanical detail, that satisfactory designs emanate almost exclusively from establishments where test flying is carried out.

A classical difficulty is the establishment of the true vertical with respect to the earth's surface, since no instrument can distinguish gravity from linear acceleration.

The gyroscope offers the most obvious solution in principle, but its application is difficult in a frame which departs from steady motion so abruptly as an aeroplane in stormy flight.

An interesting example of adaptation is afforded by the compass, in which the disconcerting " Northerly turning error " of a magnetic compass, of high natural frequency suitable for shipboard, is reduced to reasonable proportions by using a needle of low natural frequency.

The serious effect of vibration of the supporting pin as transmitted to the needle through the bearing cup of the needle was eliminated by interchanging pin and cup—Sir H. Darwin's elegant solution of trouble arising in a mechanical detail.

Accelerometers have an essential part in testing aeroplanes which are subject to acceleration several times greater than that of gravity, in aerobatic flight.

It is not easy to forecast the ultimate terms of repayment by aeronautics of its instrumental debt to other branches of engineering science.

New Askania Integrating Machines. (J. Picht, Z. Instrum., No. 7, July, 1932, pp. 289-299.) (6.0/25016 Germany.)

A technical description of several new mechanical integrating devices is illustrated by photographs and diagrams.

The elementary mathematical principles are discussed in application to types of single, double and triple integrals.

The Theory of the Frahm Vibration Indicator. (W. Meyer, Ann. d. Phys., Vol. 15, No. 1, Oct., 1932, pp. 1-27.) (6.104/25017 Germany.)

A number of flexible steel rods, loaded at the free end and clamped at the other end, are mounted in a box which can be fixed to a vibrating structure.

A mathematical investigation is given of the forced vibrations imposed by external periodic disturbances. Conversely, the observed response of the rods gives a measure of the periods and amplitudes of an external disturbance.

Scratch Extensometers. (Ind. and Eng. Chem., News Edn., Vol. 10, No. 20, 20/10/32, p. 259.) (6.262/25018 U.S.A.)

A photograph shows the instrument small enough to be held in the palm of the hand and weighing less than an ounce. A white diamond cutting point scratches records on a steel strip.

Apparatus for Determining Moments of Inertia. (W. Späth, Z.V.D.I., Vol. 76, No. 13, 26/3/32, p. 326.) (6.28/25019 Germany.)

The massive body is placed horizontally on a cradle mounted on a vertical spindle and oscillating under spring control. The position is adjusted until a minimum reading indicates that the c.g. lies in the axis of the spindle. A photograph shows the instrument with an ogival shell mounted for testing.

Three references.

On the Measurement of Oscillations in Technical Processes. (E. Lehr, Z.V.D.I., Vol. 76, No. 44, 29/10/32, pp. 1065-1073.) (6.48/25020 Germany.)

A wide range of instruments is discussed. The field of research in civil and in mechanical engineering includes machinery under the action of continuous or periodic forces and foundations and buildings subjected to sudden non-periodic disturbances.

An indicator of engine stresses measures the torsion of a crankshaft under load over the whole length or over the various crank throws.

76 references (covering the last five years).

Design of Automobile Steering Gear. (R. Wichtendahl, Autom. Ind., Vol. 67, No. 14, 1/10/32, pp. 416-422; also Autom. Tech. Zeit., No. 17, 10/9/32, pp. 409-410.) (6.55/25021 U.S.A.)

Undue yawing ("shimmy") vibrations in a new design led to systematic investigation of the geometry of seven steering gear linkages. Notable differences are shown graphically.

Tyre pressure and shock absorber setting were also varied systematically.

A three component vibration recorder was designed and applied under road conditions and a fair practical solution was obtained by trial and modification.

The ultimate dynamical causes have not been completely elucidated.

Automobile Steering Linkage. (H. Lenk, Autom. Tech. Zeit., Vol. 35, No. 12, 25/6/32, pp. 294-299.) (6.55/25022 Germany.)

The kinematics of the steering gear linkage is discussed in terms of differential geometry, and the characteristics are exhibited graphically.

The Employment of Extensometers in Aircraft Construction. (G. Ivanow, L'Aéron., No. 157, June, 1932, pp. 187-191.) (5.18, 6.56/25023 France.)

The Huggenberger extensometer is shown attached by wire springs, wire clip or electromagnet to the strained part. The wire attachment is useful for measuring the deformation of large thin sheets, such as metal wing coverings. The instrument is accurate and easy to use on the ground, but unsuitable for flight tests.

A D.V.L. instrument is recommended for flight tests and records the deflection directly by fine diamond scratches on a glass or celluloid plate.

Measurements of Acceleration and Retardation in Motor Cars. (Gastberger and Geisenhof, Autom. Tech. Zeit., Vol. 35, No. 16, 25/8/32, pp. 385-388.) 6.73/25024 Germany.)

Descriptions are given of a number of accelerometers controlled by gravity or by springs. The ambiguous interpretation of readings of gravity controlled instruments is briefly discussed.

Photo-Elasticity. (M. M. Frocht, Sci. Am., Vol. 147, No. 5, Nov., 1932, pp. 280-283.) (6.86/25025 U.S.A.)

The popular historical summary is beautifully illustrated, but weak in physics. A process of annealing " Bakelite " and the use of monochromatic light have, in the author's hands and opinion, made stress optical methods really practicable for the first time.

(The peculiarities of commercial " Bakelite " have long been familiar to physicists—the relatively high but unstable photo-elastic sensitivity, the vagaries of annealing and the natural colour tints which obscure the interpretation of the stress optical colours and make the use of monochromatic light rather a necessity.)

Engines, Thermodynamics

Thermodynamics (Velox Boiler Calculations). (Engineering, Vol. 134, No. 3486, 4/11/32, p. 539.) (8.10/25026 Great Britain.)

A paradoxical calculated efficiency of 102 per cent. is explained by the inconsistency of the steam tables used. An inconsistency is quoted from a standard book of reference.

Catalytic Oxidation of Engine Exhaust Gases. (Chem. Absts., Vol. 26, No. 22, 20/11/32, p. 6104.) (8.15, 8.723/25027 U.S.A.)
U.S. Patent 1875024, *Aug.*, 1932.

An apparatus is described for oxidising Co in the exhaust gas by metal catalysts, such as Ni, Co, Mn or Fe.

Engines, Design

Development of the Light Oil Engine for Motor Cars and Aeroplanes. (W. Schwerdtfeger, Autom. Tech. Zeit., Vol. 35, No. 14, 25/7/32, pp. 348-350.) 8.2/25028 Germany.)

An output cefficient is defined as the product of power by m.e.p. divided by the cylinder volume.

Data are compiled in four tables comprising 21 air-cooled aero engines, 29 water-cooled aero engines, 26 motor car engines and 22 motor lorry engines.

The weights are also plotted against r.p.m. and show heavy scattering of the points.

Two of the motor car engines have the 2-stroke cycle and the formula of reduction takes this into account.

General tendencies only are indicated.

The D.K.W. 15 h.p. Light Aeroplane Engine. (Luftwacht, No. 11, Nov., 1932, pp. 469 and 477.) (8.20/25029 Germany.)

The D.K.W. firm have adapted for aeroplane work their standard 2-stroke light car engine. The power plant weighs 90lb. including 5/2 reducing gear and develops 15 h.p. at 3000 r.p.m.

A photograph (p. 469) shows a Messerschmitt M.33 light aeroplane equipped with this engine. The airscrew axis is mounted above the parasol wing and driven by a cardan shaft. The engine is housed in the cockpit.

The conventional fuselage is replaced by a single steel tube carrying the airscrew at the forward end and the tail unit at the after end. High airscrew efficiency is attained.

2-*Stroke (Carburettor) Engine without Scavenge Loss.* (P. Schauer, Autom. Tech. Zeit., No. 15, 10/8/32, pp. 372-375.) (8.21/25030 Germany.)

The Schauer 2-stroke has two pistons working in almost parallel cylinders and operating on a common crank (so-called U-type).

The pistons are of unequal diameter, the smaller one acting mainly as exhaust valve for the cylinders and inlet valve for the crankcase, the larger one controlling the transfer ports from crankcase to cylinders. These ports are shaped to give the explosive mixture a rotary motion, so that centrifugal forces impose a distribution of the fresh mixture round the cylinder wall during the scavenging period, while the non-rotating core of exhaust gases is driven out axially.

The effectiveness of the device is taken to be confirmed by specific fuel consumptions approaching the results of the 4-stroke cycle over a certain speed range. Outside this range increasing specific fuel consumption indicates more serious mixture losses during scavenging.

(Abstractor's Note:—Since the spinning fluid passes round the V, the conservation of angular momentum will produce complicated fluid motions very different from the clear-cut separation of new charge from exhaust gases suggested by the inventor.)

Supercharged Marine Engines. (Autom. Ind., Vol. 67, No. 15, 8/10/32, pp. 450-451.) (8.235/25031 U.S.A.)

A technical descriptive account is given of the supercharging equipment of the holder of the world's motor boat record.

The power was increased from 1000 h.p. at 2340 r.p.m. to 1450 h.p. at 2400 r.p.m., each of two compressors feeding one bank of six cylinders. The compressors were geared up in the ratio 1.86.

In a further development the compressors were geared up to twice the engine speed and increased the output to 1650 h.p. at 2600 r.p.m. A number of technical details are given.

A photograph and section drawing show the general arrangement.

Engines, Diesels, Etc., and Accessories

Experiments on the Diesel Engine. The Reaction Kinetics of Ignition. (K. Neumann, Z.V.D.I., No. 32, 6/8/32, pp. 765-770.) (8.10/25032 Germany.)

During the delay period in the ignition process the fuel receives heat by radiation, conduction and oxidation.

An attempt is made to separate these effects. Air density affects heat transfer, oxidation and, in a striking manner, the ignition temperature. It is held that ignition is initiated in the gaseous phase, contrary to general opinion.

Good fits are obtainable with experimental curves, by judicious choice of arbitrary coefficients. None the less the article shows that there is a physical and chemical basis amenable to thermodynamic investigation which may serve to correlate the vast body of experimental data accumulated in numerous research institutes.

High Performance Diesel Engine. (Z.V.D.I., Vol. 76, No. 34, 20/8/32, pp. 819-820.) (8.25/25033 Germany.)

Messrs. Sulzer have developed a new series of 3-cylinder, 2-stroke engines, with air injection, giving from 1500 h.p. single acting to 6000 h.p. double acting at 300/400 r.p.m. With a patent welded steel plate construction for the crankcase the low weight of 25lb. per h.p. is attained for I.M.E.P. less than 100 lb./sq. in.

The same engine adapted for solid injection gives 5 per cent. less b.h.p.

Saurer Light Diesel Engine. (Autom. Tech. Zeit., No. 10, 25/5/32, pp. 253-254.) 8.25/25034 Germany.)

The engine has 4-cylinder 100 by 130 m/m. giving 55 h.p. at 2400 r.p.m., with Acro air chamber ignition and Bosch fuel pump. The cylinders have easily replaceable cast-iron liners. The crankshaft derives high stiffness from circular webs housing bearings of stiff construction. A vibration damper is fitted.

Electrical Accessories for Aircraft Engine. (W. Brintzinger and B. Bruckmann, D.V.L. Report No. 291, D.V.L. Year Book, 1932.) (8.28/25035 Germany.)

Battery ignition and magneto ignition are compared in detail. Magneto installation of the new Bosch Inductor type is considerably lighter for equal reliability than battery ignition. Automatic variation of ignition timing is obtained from two independent interruptors displaced relative to one another, and one or other of which is shorted, to give the required timing.

New insulating porcelains have greater heat conductivity than mica. This property increases the working temperature range of the plug and reduces the fouling difficulties.

Nine references.

Magneto Interchangeable with Coil Ignition. (Autom. Absts., Vol. 10, No. 11, Nov., 1932, p. 436; Motor Transport, 24/9/32, p. 3.) (8.28/25036 U.S.A.)

The Scintilla Magneto Co. have produced a new vertical drive magneto which is of similar dimensions with and can replace the normal coil ignition combined make and break and distributor.

Pressure Combustion for Steam Boilers Working in Conjunction with Gas Turbines. (W. G. Noack, Z.V.D.I., Vol. 76, No. 42, 15/10/32, pp. 1033-1039.) (8.294/25037 Germany.)

The exhaust gases leaving the Brown Boveri Velox Boiler drive a gas turbine with a direct coupled compressor which compresses the fuel gases and combines pressure combustion with high gas speeds. The whole installation is light and compact.

Installations in Continental works have shown an overall boiler efficiency of the order of 90 per cent.; are light and compact and start from cold in a few minutes. The characteristics may well enable the steam turbine to maintain active competition with Diesel engine installations.

Notes on Notch Effects. (G. Storz, Autom. Tech. Zeit., Vol. 35, No. 13, 10/7/32, pp. 324-325.) (8.35/25038 Germany.)

One condition of the success of the Maybach engines fitted to the Graf Zeppelin was the avoidance of sharp regressive edges.

Details of construction are shown in 13 sketches, in each of which the maximum feasible radius is given to re-entrant edges.

In one case the strength of the shaft was as low as 28 per cent. after cutting ordinary screw threads and as high as 58 per cent. with specially large radius at the re-entrant angle.

A lengthy discussion follows, in which modified diagrams of a similar nature are reproduced.

Torsional Vibration Damper, Vickers. (Sandner Patent). (Engineer, Vol. 154, No. 4001, 16/9/32, pp. 286-7; also Engineering, Vol. 134, No. 3486, pp. 531-2.) (8.36/25039 Great Britain.)

A photograph and sketches of section and side elevation illustrate a brief technical account of principles and design. A loose flywheel is coupled through gear wheel pumps which discharge oil against spring loaded valves when the relative acceleration of shaft and flywheel exceed a determinate figure.

Torsionograph diagrams show three undamped vibrations and one damped with notable reduction of amplitude.

A Method for Reducing the Temperature of Exhaust Manifolds. (A. W. Schey and A. W. Young, U.S.A. Technical Note No. 390. Reviewed in L'Aéronautique, No. 160, Sept., 1932, p. 283.) (8.420/25040 France.)

The exhaust pipe is designed so that the exhaust gases suck in fresh air which reduces the temperature of the collector on a radial engine by more than 100°C. There is an increase in the noise of the exhaust.

Engines, Lubricants

Lubricating Oil. (Chem. Absts., Vol. 26, No. 19, 10/10/32, p. 5201.) (8.5/25041 U.S.A.)

U.S.A. Patent No. 1867695, *July, 19th,* 1932.

Improved lubrication is obtained by the addition of app. 1 per cent. of Pb. salts of oleic and sulforicinoleic acids to the lubricating oil.

U.S.A. Patent No. 1867968, *July, 19th,* 1932.

Diphenylene oxide is a suitable lubricant for high temperature cylinder lubrication.

U.S.A. Patent No. 1868053, *July 19th,* 1932.

Hg. Cyanide in glycerol is mixed with the lubricant in order to prevent pre-ignition in an internal combustion engine (the chemical presumably influences the formation of hot spots).

Regenerated Lubricating Oil. (R. Ascher, Autom. Tech. Zeit., Vol. 35, No. 1, 10/1/32, p. 20.) (8.54/25042 Germany.)

Lubricating oil during use undergoes changes, mainly due to the formation of active products which, up to a point, improve the quality or oiliness of the oil.

Comparative Tests of Lubricating Oils in Combustion Engines. (Dipl. Ing. Kelling, Z.V.D.I., Vol. 76, No. 45, 5/11/32, pp. 1099-1102.) (8.54/25043 Germany.)

The quality of lubricating oil is " rated " by measuring the wear of the piston rings in an engine run under standard conditions of load, speed and duration. The wear is estimated by the loss in weight. A table shows appreciable differences between various oils.

Engines, Fuels, Etc.

Device for Mixing Fuels. (F. Neuroth, Z.V.D.I., Vol. 76, No. 45, 5/11/32, pp. 1109-1110.) (8.6/25044 Germany.)

In using a mixture of two fuels (*e.g.*, benzol and petrol) it is convenient to keep the original fuels in separate tanks and mix as required.

When the mixing is carried out by two constant speed centrifugal pumps, the relative delivery may be affected by partial gasification in the pipe line under reduced pressure.

This difficulty is avoided by using the special throttling device here described.

Fuel. (Chem. Absts., Vol. 26, No. 21, 10/11/32, p. 5750.) (8.6/25045 U.S.A.) *Canadian Patent* 325188/9, *August* 16*th*, 1932. *Standard Oil Co.*

The patent refers to the stabilisation of vapour phase cracked spirit with reference to gumming. Suitable inhibitors are aminophenol and phenylenediamine.

Hydrogenation of Petroleum. (P. J. Byrne, E. J. Gohr and R. T. Haslam, Ind. and Eng. Chem., Vol. 24, No. 10, Oct., 1932, pp. 1129-1135.) (8.602/25046 U.S.A.)

The production of hydrogen of high purity from natural gas (CH_4) with many details of equipment, maintenance or output is of minor interest to countries without supplies of natural gas. The output in a working year was 250,000 cubic metres.

The hydrogenation of crude low quality distillates is also described at length and extensive data are tabulated. Gasolines thus produced have high octane numbers and the resulting lubricating oils are of high grade. The solvent naphthas are applied as diluents for lacquers, paints, varnishes and as solvents for resins.

The paper offers a survey of the development of large scale hydrogenation in the U.S.A. and, in particular, of the production of safety fuel for aviation.

Combustion of Fuel Air Mixtures. (Prof. Wawrziniok, Autom. Tech. Zeit., No. 10, 25/5/32, pp. 263-266, continued in Nos. 11-14.) (8.64/25047 Germany.)

A numerical example is worked out to illustrate the heat balance in thermochemical equations and numerical results are given for these cases.

A method of determining the excess air from the exhaust gases is developed and the experimental installation is described and illustrated by a general arrangement diagram.

Thirteen comprehensive tables show the experimental results of combustion of different fuels with a varying excess of air. The composition of explosive

mixtures and exhaust gas is given and a thermal balance is worked out. The results are also shown graphically.

A further table contains a summary of the results of bomb experiments.

Details on Operating Oxy-Hydrogen Motor. (Autom. Absts., Vol. 10, No. 11, Nov., 1932, p. 429; P. M. Sanders, Motor Transport, 8/10/32, p. 10.) 8.640/25048 U.S.A.)

In the Erren oxy-hydrogen engine the hydrogen is introduced under pressure through a mechanically operated valve which renders impossible early firing during admission.

The rapid combustion of the hydrogen makes the engine less sensitive to combustion head design and plug position than the slower burning of ordinary fuel.

Some Problems Connected with High-Speed Compression Ignition Engine Development. (C. B. Dicksee, J.R. Aer. Soc., Vol. 36, No. 261, Sept., 1932, pp. 733-787.) (8.645/25049 Great Britain.)

Knock under certain conditions of operation of compression ignition engines may be due to vaporisation of fuel oil during the delay period. The distillation characteristic of a fuel oil in conjunction with its ignition temperature is a standard of suitability in this respect. This view is not generally accepted by other experimenters in the subsequent discussion.

Apparatus for Testing Gas Containers. (G. Loeck, Z.V.D.I., Vol. 76, No. 33, 13/8/32, p. 804.) (8.682/25050 Germany.)

For visual inspection of the inner surfaces an optical system, with lamp, is inserted through the neck of the container. The field of view is large and ease of manipulation is studied.

Flexible Tubing. (G. Hatzinger, Z.V.D.I., Vol. 76, No. 23, 4/6/32, pp. 563-565.) (8.684/25051 Germany.)

Aircraft pipe line installations are subjected to fatigue failure of the tubing by vibration. Fabric tubes are free from such failure, but are heavier than aluminium tubing.

A light flexible joint for aluminium tubing has a packing piece of Durit rubber pressed between the conical pipe ends and locked by a wire clip or lock nut. Aluminium pipes jointed in this manner weighed 80lbs. less than copper piping with soldered joints in a Dornier twin-engine flying boat.

Engines, Injection Systems

Influence of Induction and Exhaust Pipe Length on Distribution. (O. Klüsener, Autom. Tech. Zeit., Vol. 35, No. 12, 25/6/32, pp. 299-301.) (8.7/25052 Germany.)

A sketch shows the intake and distribution pipes of a four-cylinder engine.

Elementary expressions for pressure drop are formed for the variations in pressure and diagrams show the fourth and eighth harmonics, above, below and at resonance.

Calculated and observed deliveries of gas to the cylinders as functions of intake pipe length are compared graphically and both exhibit a maximum where the resonance effect is additive, but there is a considerable difference in the corresponding length of intake pipe, on account of the simplifying assumptions made.

Similar consideration is given to variation of pressure in the exhaust system. Difficulties of interpretation are briefly discussed.

Engines, Pumps, Etc.

Piston Compressors for Scavenging and Supercharging. (L'Aéron., No. 157, June, 1932, pp. 163-169.) (8.745/25053 France.)

The centrifugal fan supercharger, in spite of intensive development work by a number of leading engine manufacturers, remains definitely unsuitable above 15,000 feet. For high altitude flying positive blowers of various types become necessary. The article describes a double-acting piston blower, bore 29 cm., stroke 10.5, with two opposed pistons driven at engine speed (1700 r.p.m.); swept volume 27 litres.

Both inlet and discharge valves are automatic; as many as 672 flap valves are fitted. The construction is thus necessarily vulnerable and the efficiency obtained so far is low. If in spite of this drawback the designer finds justification for heavy research expenditure the need for a supercharger operating above the 15,000 feet limit of the centrifugal fan must be urgent.

Flow and Valve Motion in High-Speed Compressors. (E. Lanzendörfer, Z.V.D.I., Vol. 76, No. 14, 2/4/32, pp. 341-345.) (8.745/25054 Germany.)

An experimental valve is shown in cross section. The ratio of the actual flow to the ideal adiabatic flow is taken as the characteristic of delivery and these are exhibited graphically.

The valve position and the pressure distribution are shown for a cycle.

Thirteen references.

Valve Operation by Oil Pressure. (W. Stieber, Z.F.M., Vol. 23, No. 18, 28/9/32, pp. 536-539.) (8.745/25055 Germany.)

In the proposed design the valve is opened and closed by a double-acting piston fitted to the stem and operated by oil pressure. One pump, with spring loaded piston, maintains constant pressure on the closing side; a second pump driven by the camshaft imposes timed impulses on the opening side. A number of valves may be operated simultaneously without a multiplication of rockers, push rods and springs.

The simplification is marked in application to the swash plate drive. A description is given of various forms of oil gear operated valves, including valve gear for swash plate drive, which still appears somewhat complicated. The compressibility of the oil produced difficulties at the relatively low speed of 1200 r.p.m. and failure occurred from the formation of air bubbles, especially as the oil became hot.

The gear is considered unsuitable for aero engines, but may be successful on large stationary engines.

Engines, Transmission

Elastic Shaft Couplings. (W. Muller-Keuth, Z.V.D.I., Vol. 76, No. 36, 3/9/32, pp. 869-870.) (8.765/25056 Germany.)

The Eleard coupling consists of two toothed sections which engage with a cylindrical connection piece. The latter is split in the middle and the drive is transmitted through flat spring steel strips which take up the torque elastically for any likely angular displacement.

Screw Gauging. (G. Berndt, Z. Instrum., No. 7, July, 1932, pp. 307-319, and No. 9, Sept., 1932, pp. 408-416.) (8.769/25057 Germany.)

A discussion is given of the geometrical and mechanical principle of gauging multiple thread screw cutters in development of Valentine's published method.

In the second part a wide range of observed figures is given with a discussion of errors and corrections.

Engines, Starting Systems

Starting Engines by Compressed Air. (H. Heck, Autom. Tech. Zeit., Vol. 35, No. 15, 10/8/32, pp. 375-376.) (8.78/25058 Germany.)

Reference is made to the steady progress in France of compressed air starting.

Photographs and sectional diagrams show details of a piston compressor and driving motor.

The name plates of the apparatus are English.

Armaments

Range Finders with Invar Base. (F. Ackerl, Z. Instrum., No. 9, Sept., 1932, pp. 393-400.) (9.64/25059 Germany.)

The instrument is described and illustrated by photograph and sketch.

Extensive tables of observed and measured distances are given.

In topographical work, the mean error for four observations is .015 per cent. for distances of the order of 100 m.

Materials, Characteristics

Alloy Steels. (E. Eichwald, Autom. Tech. Zeit., No. 15, 10/8/32, pp. 363-369.) (10.1/25060 Germany.)

Particulars of 155 German alloy steels are tabulated. The values given include:—

1. Elastic properties.
2. Heat treatment.
3. Chemical constituents.
4. Name of firm producing steel.

A chrome nickel molybdenum steel for crankshafts shows a yield point at 72 tons/sq. in. with an ultimate tensile strength of 90 tons/sq. in.

Centrifugal Steel Moulds. (S. L. Conner, Sci. Am., Vol. 147, No. 3, Sept., 1932, pp. 160-162.) (10.1/25061 U.S.A.)

A descriptive technical account is given of the application of centrifugal moulds to production of cast steel cylinder for 3in. A.A. guns. Photographs show the whirling machine, moulds, pouring ladle and castings.

Radial analyses at breech, mid-barrel and muzzle are given and show a favourable distribution of carbon content caused by segregation under centrifugal forces.

A great saving in time and a marked improvement in quality are claimed. The method may have application to engine cylinders.

Two-Ply Stainless Steel. (S. L. Ingersoll, Autom. Ind., Vol. 67, No. 13, 24/9/32, pp. 392-3.) (10.102/25062 U.S.A.)

A brief descriptive account is given of a process of rolling a sheet of stainless steel on a plate of mild steel. Gas or electric welding methods are applied, and it is stated that a perfect weld is obtained.

Numerous difficulties were met with in developing the method.

The cost is favourable and numerous applications are suggested.

Tensile Properties of Some Ferrous Alloys at High Temperatures. (W. Kahlbaum and L. Jordan, Bur. Stan. J. Res., Vol. 9, No. 3, Sept., 1932, pp. 327-332.) 10.103/25063 U.S.A.)

A low carbon manganese steel, five nickel chromium iron alloys, three tungsten chromium vanadium steels and four molybdenum chromium vanadium

steels tempered at temperatures ranging from 790°C. to 840°C. were tested at temperatures ranging from 20°C. to 540°C. As a rough average the proportional limit fell two-thirds and the ultimate strength by one-third.

The detailed results are tabulated and the somewhat unsystematic results are discussed.

Creep in Chromium Vanadium Steels at High Temperatures. (W. Kahlbaum and L. Jordan, Bur. Stan. J. Res., Vol. 9, No. 3, Sept., 1932, pp. 441-455.) (10.103/25064 U.S.A.)

The composition and heat treatment of the specimens are given.

The results are exhibited graphically and show creep for times ranging up to 1000 hours for temperatures ranging up to about 600°C.

Cracking and Fracture in Rotary Bending Tests. (F. Bacon, Engineering, Vol. 134, No. 3480, 23/9/32, pp. 372-376.) (10.104/25065 Great Britain.) Paper read before British Assn., York, 7/9/32.

A full account is given of the apparatus and a number of specimens are shown in plan and section in dimensioned sketches. To simulate working conditions more closely the amplitude of the load can be given a long period variation.

A wide range of the somewhat erratic phenomena of development of cracks and final rupture is considered critically. Test curves of endurance are reproduced. The study of the history of a crack is facilitated by " heat-tinting " and the result of such an analysis is given in a diagram representing the history of a case.

Elongation Line Method for Determining the Distribution of Stresses in Engine Parts Under Alternating Stress. (O. Dietrich and E. Lehr, Z.V.D.I., Vol. 76, No. 41, 8/10/32, pp. 973-982.) (10.104/25066 Germany.)

The firm of Maybach, builders of the airship engine, have prepared a varnish which is applied to working parts of engines and which cracks when the surface is strained under load.

The extension under static load is measured with an extensometer clamped to the engine part with a base line of 2 mm. to 15 mm. Illustrations exhibit the cracking of the varnish as an indication of stresses in crankshafts, connecting rods and pistons.

Fifteen references.

Iron-Cored Coils for Radio Frequencies. (Wireless World, Vol. 31, No. 11, 16/9/32, pp. 272-3.) (10.105/25067 Great Britain.)

Under German patents a magnetic dust, " Ferrocart," is packed between paper laminations to form the core of induction coils which are compact and easily screened. Rights of manufacture have been arranged in this country. (See " Nature," Nov., 12th, 1932, p. 748.)

Materials, Defects and Treatments

Flakiness in Structural Steels. (W. Eilender and H. Kiessler, Z.V.D.I., Vol. 76, No. 30, 23/7/32, pp. 729-735.) (10.12/25068 Germany.)

Flaking of steel is due to internal strains and stresses concomitant with local recrystallisation, accentuated by unequal cooling, in the final stages. Accurate control of heat treatment before final rolling and forging is required.

Steel Hardening by Nitrogen. (Tech. Aéron., No. 124, 1932, pp. 99-105.) (10.12/25069 France.)

The French Hispano-Suiza firm were early in adopting the process on a large commercial scale and some account of their experiences is given. In particular, nitrogen hardening of cylinder liners increases their life and reduces oil consumption substantially.

Nitrogen Hardening of Alloy Steels. (O. Meyer and W. Eilender, Z.V.D.I., Vol. 76, No. 13, 26/3/32, pp. 317-320.) (10.12/25070 Germany.)

Consideration is restricted to the newer processes of surface hardening of special steels by exposure to gases giving off nitrogen at comparatively low temperatures. Specifications are given of a steel hardened by the old methods of cementation by simultaneous introduction of carbon and nitrogen through suitable materials, and of the steels suitable for the modern process of nitrogen hardening, one exhibiting extreme surface hardening without internal strain, the other moderate hardening with greater malleability.

The chemical physical processes involved in hardening these and other successful steels are discussed in considerable detail.

Excessive carbon content hinders the diffusion of nitrogen and undesirable quantities of vanadium, chromium and molybdenum carbides may be formed.

The introduction of titanium as a supplementary metal has given remarkable degrees of hardness.

Methods of reducing the somewhat lengthy time of diffusion of nitrogen are considered, in particular by heating by alternating current. An increased quantity of nitrogen is diffused in a given time, but the depth of the nitrated layer is not much affected.

Twenty-two references.

Heat Treatment. (J. Geschelin, Autom. Ind., Vol. 67, No. 10, 3/9/32, pp. 291-2 and 316.) (10.12/25071 U.S.A.)

A full schedule of steel specifications and heat treatments is given by the courtesy of C. B. Brull, Director of the Citroen Co.'s laboratories.

Water-Cooled Electrodes (for Spot Welding). (G. N. Sieger, Autom. Ind., Vol. 67, No. 16, 15/10/32, p. 481.) (10.140/25072 U.S.A.)

It is stated that water-cooled electrodes designed by the author have longer life and give more consistently accurate welds. Sketches illustrate his views on correct and incorrect design.

Steel Dies, Gas-Cut and Welded. (E. Chapman, Autom. Ind., Vol. 67, No. 17, 22/10/32, pp. 530-532.) (10.140/25073 U.S.A.)

Seven photographs illustrate the building up of steel dies by welding, from parts cut out by gas jet flame. It is stated that the weight and cost are reduced.

Structural Changes of Alloys. (Z.V.D.I., Vol. 76, No. 30, 23/7/32, p. 724.) (10.26/25074 Germany.) Symposium of papers submitted to German Society for Metal Research, June, 1932.

Consideration is given to the so-called " incubation " period in annealing and ageing duralumin. In certain cases the polarisation microscope revealed regions of strain in the vicinity of crystalline precipitates.

The Behaviour of Light Alloys under Static and Alternating Loads at High Temperatures. (W. Schwinning and E. Strobel, Z. Metallk., Vol. 24, No. 6, June, 1932, pp. 132-137, and No. 7, July, 1932, pp. 151-153.) (10.26/25075 Germany.)

Pure aluminium and lautal are compared at temperatures up to 300°C. Lautal (4 per cent. Cu, 1 per cent. Si) is quenched at 500°C. and reheated to 150°C. It has better mechanical properties than duralumin under alternating stresses and at high temperature.

The History of the Development of Aluminium Alloys Capable of being Rolled and the Theory of the Hardening Process. (G. Sachs, Z.V.D.I., Vol. 76, No. 34, 20/8/32, pp. 829-830.) (10.26/25076 Germany.)

Duralumin alloy, of which the original (1909) patent has just expired, holds its position against a large number of aluminium alloys since produced and susceptible of heat treatment and forging.

It has been found that the heat treatment produces mixed crystals and that subsequent ageing produces a roughening of the crystal lattice work by changes in the atomic structure.

A New Aluminium Light Alloy "Chlumin." (Z. Instrum., No. 8, Aug., 1932, p. 377.) (10.26/25077 Germany.)

Good anti-corrosion qualities are claimed for a new Japanese aluminium alloy of high chromium content, susceptible of heat treatment and generally resembling duralumin in its properties.

Investigation of Tension-Corrosion Cracks in Light Alloys. (P. Brenner, Z. Metallk., No. 7, July, 1932, pp. 145-151.) (10.26/25078 Germany.)

Cracks may be due to intercrystalline corrosion. An alloy, not subject to intercrystalline corrosion, may undergo general surface corrosion with far less serious reduction of strength.

Light Metal Castings—Statical and Fatigue Strength. (W. Saran, Z. Metallk., No. 8, Aug., 1932, pp. 181-184, and No. 9, Sept., 1932, pp. 207-210.) (10.261/25079 Germany.)

Part I.

Seven aluminium alloys and one magnesium alloy were submitted to comparative tests under steady loads from small strains up to rupture.

The figures obtained under tensile heading and torsion loads are tabulated and shown graphically against the permanent residual strain.

The methods of applying alternating tests are discussed and figures for the lower ultimate strengths are given.

Part II.

In Part II. results of systematic fatigue tests on "K-S," "Alufont" and "Elektron" are exhibited graphically.

Static tests are shown in a comparative table with the five other alloys.

No simple relation is found between static and fatigue test results.

Other properties are shown graphically and include hysteresis loops in tests of "Elektron."

Activities of the Material Test Department of the D.V.L. (Luftwacht, No. 10, Oct., 1932, pp. 435-436.) (10.262/25080 Germany.)

Corrosion of Light Alloys.

Whilst ordinary dural and silumin undergo considerable reduction in ultimate tensile and extension, after six months exposure to open air sea-water corrosion, dural plat, K.S. alloy and hydroalumin (a new aluminium alloy) suffered no appreciable loss in mechanical properties.

Activities of the Material Test Department of the D.V.L. (Luftwacht, No. 10, Oct., 1932, pp. 435-436.) (10.400/25081 Germany.)

Mechanical Properties of Wood.

The mechanical properties of wood and its consistency as a structural material are considerably improved by previous doping and subsequent lamination and glueing. The plywood construction is especially to be recommended when stresses at right angles to the wood fibre are imposed. The inclusion of one or two laminations will increase four or five fold the mechanical properties of ordinary unlaminated wood sections.

Tests of Aeroplane Fabrics. (K. Schraivogel, Z.F.M., Vol. 23, No. 16, 27/8/32, pp. 489-494, and No. 17, 14/9/32, pp. 519-522.) (10.402/25082 Germany.)

D.V.L. Report 289.

The characteristics of fabrics are in general variable from piece to piece and unstable with time in the same place.

Treatment with cellulose preparations improves the immediate test figure and the durability.

Flax and cotton are the principal materials. The high cost and mechanical defects of silk offset the low specific weights.

Microscopic examination gives a preliminary idea of the quality of the fibres. Variation of characteristics with moisture content is the most serious defect of textiles.

A description is given of the various testing appliances used and the observed characteristics of eight materials are tabulated, six of linen, one of cotton and one of silk.

Test figures from some other sources are collected in another table.

Nineteen references.

Safety Glass. (B. C. Foy, Sci. Am., Vol. 147, No. 3, Sept., 1932, pp. 164-165.) (10.406/25083 U.S.A.)

A descriptive account is given of the production of multiplate glass in America, with some technical details and photographs.

Shear Moduluses of Timber Sheets and Plywood. (H. Hertel, L.F.F., Vol. 9, No. 4, 21/6/32, pp. 135-144.) (10.42/25084 Germany.)

D.V.L. Report 287.

Numerical values of the shear modulus obtained in previous work are plotted graphically. Details of the test apparatus are shown in a photograph. The methods of making the observations are specified and elementary elastic theory is applied to reducing the results and obtaining the shear modulus. Extensive data are collected in tables and exhibited graphically.

Examples of numerical reduction are worked out and specifications and tests for commercial birch plywood are given.

Properties of Impregnated and Laminated Woods. (P. Brenner and O. Kraemer, L.F.F., Vol. 9, No. 4, 21/6/32, pp. 145-152.) (10.42/25085 Germany.)
D.V.L. Report 288.

Methods of impregnating wood are discussed and figures for walnut, ash and beech show generally increased density and compressive strength, reduced tensile strength and much reduced absorption of moisture.

The properties of laminated wood are investigated and figures are tabulated for walnut, ash, beech and birch, for compressive tensile bending and torsional stresses and moduluses.

Eight photographs of fractures are reproduced and discussed.

Glued joints are also considered. Average quality and reliability are much increased by treatment and lamination.

Six references.

Surface Protection of Aeroplane Fabrics. (K. O. Schmidt, Z.F.M., Vol. 23, No. 18, 28/9/32, pp. 549-550.) 10.424/25086 Germany.)
D.V.L. Report 277.

Instructions are given for applying dope and for testing the finished fabric for strength and durability. Painting with a brush gives better results than spraying.

For European climates five coats suffice, but for tropical climates nine coats should be applied. To get a smooth finish some surface grinding is required after applying three or four coats. The last coat should be pigmented and polished. Research is proceeding on a fire-proof dope.

The Preparation and Utilisation of Finely Ground Materials in Industry. (R. Meldau, Z.V.D.I., Vol. 76, No. 28, 9/7/32, pp. 673-677.) (10.9/25087 Germany.)

Preparation by dry grinding and subsequent sorting is cheaper than by washing, heating or chemical processes. Friction between dust particles may produce explosion by discharge of static electricity in an explosive mixture. The milling of potassium stearate and palmitate produces fog by electrical repulsion of the small particles. Stone dust in a gaseous (mine) explosion may absorb enough heat to stop the chemical reaction. Soot may increase the heat by oxidation; application is made to the breaking up of ice in the spring for river navigation.

Thirty-seven references.

Wind Tunnels

The Brunswick Wind Channel. (S. Hoerner, Z.F.M., Vol. 23, No. 16, 27/8/32, pp. 486-487.) (11.10/25088 Germany.)

A brief technical description is illustrated by a general arrangement sketch and two photographs.

The channel is of the open jet closed return type and has a nozzle diameter of 1.3 m., velocity 12 m/s. to 55 m/s., motor power 120 kw.

Airships, Balloons, Etc.

High Altitude Balloon of Piccard. (C. Dollfus, L'Aéron., No. 160, Sept., 1932, pp. 267-268.) (12.19/25089 France.)

The balloon, constructed in Germany, is spherical, capacity 14,000 m^3. The fabric is rubberised cotton, of specific weight 60 gr./m^2. The gondola with passengers and equipment weighs 1200 kg. There is no balloon net; the gondola is attached by ropes to a circumferential fabric panel at about one-third balloon height.

The balloon, at ground level, is filled to about one-fifth capacity. In the first ascent the gondola was painted black and the internal temperature rose to 40°C. under the sun's rays.

In the second ascent the gondola was painted white and the internal temperature fell to 0°C. Landing even in calm weather subjected the passengers to considerable shocks. Buffers of willow twigs are proposed as landing shock absorbers.

Mooring Mast for Airships. (Aviation, Vol. 31, No. 11, Nov., 1932, p. 453; also Sci. Am., Vol. 147, No. 6, Dec., 1932, p. 358.) (12.33/25090 U.S.A.)

A photograph is reproduced of a telescopic, self-propelling mooring mast for U.S. airships. After the airship is moored the mast retracts from 160 feet to 75 feet before towing the airship into dock.

Airships. (Sci. Am., Vol. 147, No. 3, Sept., 1932, pp. 172-173.) (12.39/25091 U.S.A.)

Photographs show the aeroplane hook-on device of the Akron and the framework of the Macon under erection.

The financial problems of an airship service are briefly discussed.

Portable and Fixed Gas Generators for Filling Pilot Balloons. (F. Petz, Z. Instrum., No. 8, Aug., 1932, pp. 365-368.) (12.44/25092 Germany.)

The portable generator weighs 120 kg. and produces three cubic metres of hydrogen per hour by the action of caustic soda on silicon. The cost of chemicals is about one mark per cubic metre.

At a fixed station a supply of gas is best maintained by a small electrolytic generator working continuously on the mains, with a gasometer for storage.

Wireless

The 5th International Electrical Congress, 1932. (Z.V.D.I., Vol. 76, No. 39, 24/9/32, p. 944.) (13.0/25093 Germany.)

Although great progress has been made in the construction of pupinised telephone cables, submarine telephony is still limited to relatively short distances, since intermediate amplifiers cannot be fitted. Long distance ocean talks are made entirely by wireless. It is estimated that the total radiated power of the world's broadcasting stations amounts to 4,000 kw. which corresponds to an input of at least 25,000 kw.

Frequency Distribution of Atmospheric Noise. (R. K. Potter, Proc. Inst. Rad. Eng., Vol. 20, No. 9, Sept., 1932, pp. 1512-1518.) (13.1/25094 U.S.A.)

Author's Abstract:—A relation between atmospheric noise intensity and frequency is estimated upon the basis of noise measurement data covering the frequency range between 15 and 60 kilocycles, and two and 20 megacycles.

Eight references.

Wavelength Characteristics of Coupled Circuits. (R. King, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1368-1400.) (13.2/25095 U.S.A.)

Author's Abstract:—The wavelength characteristics of a simple circuit and of a coupled circuit regenerative oscillator having distributed circuit constants are derived for the case of small resistance and compared with experimental results. A comparison is made with analogous characteristics of circuits with lumped constants and of the electron oscillator.

Sixteen references.

Characteristics of Damped and Undamped Circuits. (M. Osnos, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 103-108.) (13.2/25096 Germany.)

The principal physical relations are summarised and the corresponding mathematical formulæ are collected in a form suitable for design calculations.

Three references.

Study of Harmonics in Tuned Circuits. (P. H. Osborn, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 813-834.) (13.2/25097 U.S.A.)

When the power output is proportional to the square of the grid voltage and the tube is biased to the cut-off point, the wave approximates to half a sinusoid. With high grid excitation biased beyond the cut-off, the current wave is peaked and extends over less than half a cycle. The latter arrangement gives rise to more intense harmonics.

The observed characteristics of three tubes are reproduced.

The elementary theory of harmonics is developed and formulæ are obtained suitable for numerical calculations.

Disturbances in Receivers. (J. W. Alexander, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 82-88.) (13.2/25098 Germany.)

Fourier's analysis is applied to elucidate the theory of disturbances. So-called Fourier sound spectra are obtained experimentally for different sources of disturbance.

Maximum permissible values of disturbances are derived for rectifier, driving motor and buzzer.

Reduction of Output Disturbances. (J. O. McNally, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1263-1283.) (13.2/25099 U.S.A.)

From Author's Abstract:—This paper discusses the disturbance currents in the output circuits of indirectly heated cathode triodes, introduced by the use of alternating current in the heaters. It indicates that the disturbance currents are introduced into the output circuit by (1) the electric field of the heater, (2) the magnetic field of the heater current, and (3) the resistance between heater and grid and between heater and plate, and the capacitance between heater and grid and heater and plate.

Disturbance currents of the frequency of the heater supply, and of double this frequency are shown to be produced by the magnetic field. The double-frequency component is shown experimentally to be proportional to the square of the heater current. The following means of reducing the magnetic field are discussed: (1) the adoption of a heater "geometry" which produces a smaller field in the space between the cathode and the plate, (2) the use of a magnetic shield around the heater system, and (3) the use of a lower current, higher voltage heater.

Ten references.

Linear Distortions in Broadcast Receivers. (A. Clausing and W. Kautter, Proc. Inst. Rad. Eng., Vol. 20, No. 9, Sept., 1932, pp. 1456-1480.) (13.2/25100 U.S.A.)

Author's Abstract:—This paper shows how the selectivity as well as the processes in the detector and low-frequency part cause distortion in broadcast receivers. The chief cause of poor fidelity must be sought in the selectivity of the tuning means. This can be raised to high values by increasing the number of tuning circuits and by improving the quality of the coils (sharpness of tuning). The need for many selection means and sharpness of tuning depends less on the desire for greater amplification than on the necessity of being able to make a good separation of radio transmissions which are close together. The usual

tuning circuits show, qualitatively, the same character of frequency drop independent of the number and sharpness of tuned circuits. Therefore in order to separate side frequencies that are comparatively close together (neighbouring transmitters), frequencies must be considerably weakened which are indispensable for tone-true reproduction. Consequently this paper shows methods which, in the low-frequency part, equalise, for the most important frequencies, what is lost in the high-frequency part. These methods will become unnecessary only when it becomes possible to build cheap, reliable radio-frequency band filters with constant band width but variable average transmission range. This is not as simple as the names applied to all possible designs would lead us to believe.

Eight references.

Measurement of Echoes from the Ionised Layer. (G. Goubau and J. Zenneck, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 77-82.) (13.30/25101 Germany.)

A brief description is given of a sender for waves of 500 m. to 1,000 m., with a photograph and diagrams of connections of the sender and of the make and break control for signals of very short duration. A similar description is given of the photographic receiving apparatus, in which the circular path of a spot of light is interrupted by the direct signal and by the echoes.

A series of photographs is reproduced on a strip of film, each exposure showing a completed circle record with disturbances inward along radii, the angular spacing showing the time between main signal and echo. (See Abstract 22620.)

Six references.

Phase Shift in Radio Transmitters. (W. A. Fitch, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 863-883.) (13.31/25102 U.S.A.)

A mathematical theory of phase shifting is worked out and leads to very lengthy expressions.

The cathode ray oscillograph was applied to determine phase shifts experimentally and three oscillograms are reproduced.

Problems in Selective Reception. (M. V. Callendar, Proc. Inst. Rad. Eng., Vol. 20, No. 9, Sept., 1932, pp. 1427-1455.) (13.32/25103 U.S.A.)

From Author's Abstract:—The equations for magnification and phase differences introduced by one or more simple tuned circuits are first obtained in a convenient form, corresponding expressions are obtained for the band-pass circuit, and a note is appended upon circuits with reaction.

The two rival systems of selective tuning, viz., the band-pass and the simple sharp tuner with audio tone correction, are compared as regards their ability to deal with the direct and also the heterodyne interference from unwanted neighbouring transmissions; the probability of frequency and harmonic distortion in the resulting reception under practical operating conditions is also discussed and it is shown in particular that the band-pass system is inferior on at least two of these four heads.

Eight references.

Theory of the Electro Magnetic Loud Speaker. (M. Kluge, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 108-111.) (13.32/25104 Germany.)

An idealised arrangement is discussed mathematically and the results are adapted to practical conditions. Some of the conclusions are opposed to current design.

Sixteen references.

Field Intensity Measurements. (S. S. Kirby and K. A. Norton, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 841-862.) (13.32/25105 U.S.A.)

Measurements made at 2.4 km. showed no appreciable absorption by the ground above 300 m. in wavelength, but below this wavelength absorption increases rapidly and intensities at 100 km. to 400 km. are only one per cent. in comparison with the intensity of cylindrical radiation.

The conductivity and dielectric coefficients east and west of the Alleghenny Mountains were determined and used to draw fair curves of intensity along which the observations lie without serious scattering.

Note on Reception at Distances Exceeding 12,000 *km.* (L. V. Berkner, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1324-1327.) 13.32/25106 U.S.A.)

From Author's Abstract:—Aural observations of broadcast stations were made during the operations of the Byrd Antarctic Expedition, in New Zealand and between New Zealand and Antarctica. Interference between very widely separated stations on the same frequency is mentioned.

Four references.

Reception of Frequency Modulated Radio Signals. (V. J. Andrew, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 835-840.) (13.32/25107 U.S.A.)

Author's Abstract:—The simplest method consists in analysing the signal into a carrier and side bands and calculating the response of the tuned circuit to each component. The maximum power response is found to be 0.09 of the response with an amplitude modulated transmitter of the same power. There is an inherent discrimination in the receiver against the lower modulation frequencies which just balances a similar discrimination in the transmitter against the higher modulation frequencies.

Action of Short-Wave Frame Aerials. (L. S. Palmer and L. L. K. Honeyball, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1345-1367.) (13.4/25108 U.S.A.)

The transmitter employs wavelengths between 7.54 and 8.80 metres, and the receiving frame is capable of expanding or contracting. Tuning is accomplished by shunting the frame with a copper strip in parallel with a condenser. The results of the measurement are compared with theory and it is concluded that max. frame current only results when the frame is both tuned and formatised.

Three references.

The Damping of Mechanical Oscillations in High Tension Wire. (Z.V.D.I., Vol. 76, No. 39, 24/9/32, p. 946.) (5.42, 13.4/25109 Germany.)

A description is given of dampers which reduce forced oscillations impressed by the wind on h.t. cables from dangerous amplitudes to negligible magnitude.

Braun Tubes at very High Frequencies. (H. E. Hollmann, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 97-103.) (13.5/25110 Germany.)

A photograph shows new constructional details. The deviation of the cathode stream is calculated and exhibited graphically for constant and alternating fields.

The sensitivity of a Braun tube is shown as a function of the frequency and as a function of the anode potential.

Phase alterations are recorded photographically.

Five references.

Current Rectification at Metal Contacts. (S. P. Chakravarti and S. R. Kantebet, Proc. Inst. Rad. Eng., Vol. 20, No. 9, Sept., 1932, pp. 1513-1534.) (13.5/25111 U.S.A.)

From Author's Abstract:—Six different contacts of dissimilar metals, Bi-Fe, Cu-Fe, Cu-Sn, Sn-Zn, Ze-Fe, and Pb-Sn, were studied for their rectifying properties. As far as possible small lengths of cylindrical rods with circular section were used. Their tips barely touched each other, producing an imperfect contact at which rectification was found to take place best.

An attempt is made to explain the rectifying property by assuming that a thermo e.m.f. develops at the contact and that the resistance of the contact itself varies with terminal voltage.

Fifteen references.

Water-Cooled High Power Vacuum Tube. (I. E. Mouromtseff, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 783-807.) (13.5/25112 U.S.A.)

The concentration of the load in a single tube is preferable to distribution over a number of tubes in parallel. This has led to the design of tubes with an output of 100 kw.-200 kw. The principal new design element is a water-cooled grid, built up of flat molybdenum discs disposed in a column.

Five photographs show the general arrangement and a number of details. The principal dimensions can be inferred from the description. The characteristics of the tube are given in eleven diagrams.

Recent Trends in Receiving Tube Design. (J. C. Warner, E. W. Ritter and D. F. Schmit, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1247-1262.) (13.5/25113 U.S.A.)

Author's Abstract:—This paper gives a brief summary of the important steps in receiving tube design over the past ten years. The significance of new forms of grids and in particular the suppressor grid are discussed. Characteristics of new radio-frequency tubes containing suppressor grids are shown. Improvements in cathode and grid designs are illustrated by the characteristics of a new triode as well as two triple-grid tubes. A new tube for Class B audio amplification is described, together with a mercury vapour rectifier for supplying power to the Class B. amplifier.

Five references.

Voltage Dividers for Cathode Ray Oscillographs. (M. F. Peters, G. F. Blackburn and P. T. Hannen, Bur. Stan. J. Res., Vol. 9, No. 1, July, 1932, pp. 81-114.) (13.5/25114 U.S.A.)

The mathematical theory of capacitance voltage dividers is given and the conditions are stated for avoiding modifications of the characteristics of the circuit by introduction of the divider. A photograph shows the arrangement of the capacities.

Thirty-five oscillographs are reproduced.

Diagrams of connections and calibration curves are given.

Gas-Filled Cathode Ray Tubes. (M. von Ardenne, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1310-1323.) (13.5/25115 U.S.A.)

A non-mathematical discussion of design problems is given, illustrated by excellent photographs and by characteristic diagram. The most suitable plate voltage should not exceed 5,000 volts for slow electrons. Initial concentration of ions is imposed by a Wehnelt cylinder. Disturbance due to ionic oscillations is reduced by a grounded metal strap round the tube. Gases of less molecular weight, particularly hydrogen, give sharper definitions at high radio frequencies.

Properties of fluorescent screens are discussed. The characteristics of the Braun tube are shown graphically.

Four references.

Recent Development of Radio-Beacons. (E. Kramer, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 88-92.) (13.6/25116 Germany.)

A brief historical account is given of developments, chiefly in U.S.A., with a map of existing air lines and beacons in that country.

Combinations of directional senders are considered in respect of the form of signals received along different radial directions.

Delimitation of Landing Grounds by Electro Magnetic Field for Blind Landing. (H. Gromoll, H.F. Technik, Vol. 40, No. 2, Aug., 1932, pp. 41-47.) 13.6/25117 Germany.)

A circular leader cable carries an alternating current of about five amperes at 2,500 cycles per second fundamental frequency and harmonics producing an approximately rectangular wave profile.

The vertical component is received by a horizontal frame aerial in the aeroplane, is amplified and rectified, giving an effective e.m.f. of one millivolt at 500 metres height and limited by a valve to a maximum of 10 millivolts.

There is an abrupt change in the phase of the vertical component along a surface of revolutions extending upwards and outwards from the leader cable, and the indication of this change by the instrument enables the pilot to locate the landing ground.

Nine references.

Radio Communication in Amsterdam on a Wavelength of 7.85 Metres. (P. J. H. A. Nordlohne, H.F. Technik, Vol. 40, No. 2, Aug., 1932, pp. 47-55.) (13.6/25118 Germany.)

An experimental system was maintained for a year, on a wavelength which was not reflected from the ionised layer.

A technical description is given of sender and receiver, with three photographs. The range in space is limited and interference between distant stations is eliminated.

The range between 7.5 metres and 7.8 metres wavelength can carry more stations without undue interference than the range from 200 to 2,000 metres. Applications to police, fire stations, fleets, armies, etc., are suggested.

Ten references.

Short-Wave Measurements in Wireless. (K. Schlesinger, H.F. Technik, Vol. 40, No. 2, Aug., 1932, pp. 68-72.) (13.6/25119 Germany.)

Reference is made to characteristic difficulties arising in combinations of instruments from capacity and reactance in the connections.

Shielding, use of concentric connectors, balancing of the earth effect by a differential condenser are applied to prevent couplings by earth currents.

Couplings with zero capacity and some special instruments are described and illustrated.

A New Type of Ultra-Short-Wave Oscillator. (I. E. Mouromtseff and H. V. Noble, Proc. Inst. Rad. Eng., Vol. 20, No. 8, Aug., 1932, pp. 1328-1344.) (13.6/25120 U.S.A.)

Author's Abstract:—A new oscillator for generating ultra-short waves, in which the conventional tank circuit is replaced by a portion of concentric transmission line, is described. Electrically, the tube structure forms an integral part

of the transmission line. For this the quantity VC/L for the tube must be the same as for the rest of the line, C and L being capacity and inductance per unit length of the line. A comparison of the closed oscillating circuit with the "standing wave oscillator" shows distinct advantages of the latter in the region of ultra-short waves. The mode of connecting the load to the oscillator is discussed. Some of the oscillator characteristics are given for wavelengths of five and three metres with 15 and 12 kw. output, respectively. Mention is made of a marked physiological effect of ultra-short-wave fields.

One reference.

Direct Ray Broadcast Transmission. (T. L. Eckersley, Proc. Inst. Rad. Eng., Vol. 20, No. 10, Oct., 1932, pp. 1555-1579.) (13.6/25121 U.S.A.)

From Author's Abstract:—The paper is written with a view to enabling predictions to be made as to the field strength of direct-ray transmission on wavelengths between 60 metres and 2,000 metres.

The main part of the paper is concerned with daylight transmission. The question of night transmission and the influence of the Heaviside layer is considered briefly at the end.

Copper-Oxide Rectifier Used for Radio Detection and Automatic Volume Control. (L. O. Grondahl and W. P. Place, Proc. Inst. Rad. Eng., Vol. 20, No. 10, Oct., 1932, pp. 1599-1614.) (13.7/25122 U.S.A.)

From Author's Abstract:—A new type of radio detector has been developed which depends for its action on the rectifying properties of the boundary between copper and cuprous oxide formed on the copper at a high temperature.

The circuits developed possess unique advantages in that harmonic distortion is practically eliminated, a stage of audio-frequency amplification is eliminated and automatic volume control is achieved without the necessity of using an auxiliary tube.

Seven references.

Time Lag in Photocells. (N. R. Campbell, Phil. Mag., Vol. 14, No. 91, Sept., 1932, pp. 465-486.) (13.7/25123 Great Britain.)

Vacuum photocells are free from time lag, gas-filled cells under certain conditions show time lags of the order of 1/6000 sec. The time lag may be inferred from the behaviour of the cell when exposed to fluctuating light or measured directly as in an apparatus described. After testing a number of different cells the author reaches the conclusion that the result cannot be correlated satisfactorily by any known theory. In the words of the author it seems of little use to investigate time lag till more is known of the Townsend discharge.

Visual Test Devices. (O. H. Schuck, Proc. Inst. Rad. Eng., Vol. 20, No. 10, Oct., 1932, pp. 1580-1598.) (13.80/25124 U.S.A.)

From Author's Abstract:—A device for showing on a screen the frequency-response curve of a tuned circuit, tuned transformer, amplifier or complete radio set is described in this paper. The action of the device is practically instantaneous, and the effect of circuit adjustments may be seen immediately.

Five references.

A New Electrical Method of Frequency Analysis and Its Application to Frequency Modulation. (W. L. Barrow, Proc. Inst. Rad. Eng., Vol. 20, No. 10, Oct., 1932, pp. 1626-1639.) (13.80/25125 U.S.A.)

From Author's Abstract:—The resolving power of the method is very high, allowing component voltages of only two cycles per second frequency difference to be clearly resolved.

A simple expression for the spectrum of a wave with both amplitude and frequency modulation is derived, which allows an immediate oversight of the changes in side band magnitude occurring when one type of undesired modulation accompanies the other. Finally, the relation of the oscillogram of superposed constant frequency and search voltages to Lissajou's figures is pointed out, and a comparison with diatonic harmony made.

Eight references.

Vibrations of Quartz Plates. (R. B. Wright and D. M. Stuart, Bur. Stan. J. Res., Vol. 7, No. 3, Sept., 1931, pp. 519-553.) (13.81/25126 U.S.A.)

A summary of crystal elasticity is given with reference to quartz.

Glow discharge patterns and dust patterns for similar modes showed little resemblance.

The optical method is not considered to be readily adaptable. (See Abstract 24917.)

Over eighty photographs of patterns are reproduced. Improvements in the practical mounting of quartz plates and rods are suggested.

Piezo-Electric Shotgun Pressure Indicator. (C. T. Ervin, Army Ordnance, Vol. 13, No. 74, Sept./Oct., 1932, pp. 99-101.) (13.81/25127 U.S.A.)

A descriptive technical account is illustrated by photographs and a diagram.

Two oscillograms are reproduced, one showing a calibration record, the other two superposed explosion pressure records with damped and undamped elements.

Vibrations of Quartz Plates. (R. C. Colwell, Proc. Inst. Rad. Eng., Vol. 20, No. 5, May, 1932, pp. 808-812.) (13.81/25128 U.S.A.)

A comparison is made between the nodal lines in a quartz plate and the Chladni lines on brass plates, by means of selected examples. Dissimilarities are noted as might have been expected, since quartz crystals have six elastic constants, while brass may be considered as an isotropic material with only two elastic constants.

Metal Shielding Against Alternating Magnetic Fields. (H. Kaden, H.F. Technik, Vol. 40, No. 3, Sept., 1932, pp. 92-97.) (13.9/25129 Germany.)

A mathematical analysis is given for parallel plates and a sphere, and the numerical results are exhibited in eight diagrams.

Ten references.

Photography

The D.V.L. Zeiss Photochronograph. (L'Aéron., No. 157, June, 1932, p. 179.) (14.28/25130 France.)

Enough film is carried for eight complete records of landing and starting. The trajectory of the aircraft can be plotted with accuracy for distances from the apparatus of 100 to 300 metres.

Infra-Red Spectra. (W. F. Meggers and C. C. Kiess, Bur. Stan. J. Res., Vol. 9, No. 3, Sept., 1932, pp. 309-326.) (14.50/25131 U.S.A.)

A new dye, xeno-cyanine, is used to render photographic plates sensitive to infra-red light.

A mass of new ultra-red wavelengths is tabulated for Ti, Fe, Co, Ni and Zr. Many projected lines are observed for the first time.

Aerial Photographs of Very Distant Objects. (L'Aéron., No. 160, Sept., 1932, p. 269.) (14.50/25132 France.)

Photographs taken in California by the U.S. Navy at an altitude of 16,000 feet with special sensitised plates and filter show the curvature of the horizon, distant about 300 miles. The plates were 18 by 24 mm., exposure 1/25 sec. The method may have applications to long range survey of enemy territory.

Photography. (D.V.L. Reports.) (Luftwacht, No. 7, July, 1932, p. 287.) 14.50/25133 Germany.)

By the use of infra-red plates with suitable colour filters in a zenith camera the light of the sky is intercepted and infra-red rays from the sun reflected by the aeroplane are recorded. In this way a number of positions of the aeroplane can be recorded on the same plate by successive exposures. The need of a sky absolutely clear of cloud imposes a severe restriction. (See Abstract 22542.)

Craft Location

Theodolites. (D.V.L. Reports.) (Luftwacht, No. 7, July, 1932, p. 287.) (15.10/25134 Germany.)

In conjunction with the Askania and Zeiss firms several new self-recording theodolites have been designed. The observer keeps the aeroplane in view and the altitude and azimuth are recorded photographically at intervals (see Abstract 24919). One altitude and two azimuths or two altitudes and one azimuth are sufficient for a fix. Two instruments give three redundant readings as checks and ensure a high order of accuracy. In another arrangement synchronised photographs from the wing tips yield accurate data for determining speed near the ground during start and landing.

Influence of Atmospheric Conditions Upon the Audibility of Fog Signals. (B. R. Hubbard, Phys. Berichte, No. 18, 15/9/32, p. 1658; J. Acoustical Soc. of America, Vol. 3, No. 1, Part 1, 1931, pp. 111-125.) (15.20/25135 Germany.)

The reception measurements of fog signals emitted from a lightship are compared with the calculated effects of temperature and of wind gradient in a vertical direction.

Acoustical Methods of Position Fixing. (G. Foges, Z.F.M., Vol. 23, No. 17, 14/9/32, pp. 508-510.) (15.20/25136 Germany.)

An aeroplane flying on radio direction is notified of the proximity of the aerodrome by a rapid increase in radio signal intensity. It then transfers to aural signals which are emitted continuously from the ground. The direction is determined by the phase difference of the sound as received by two microphones placed at a distance of 3 m. on the aircraft and connected to the observer by aircups.

The microphones have a resonance period near 1200 Hertz and the frequency of the sound signal is varied periodically through this value, so that the difficulty of maintaining exact tuning is avoided.

Sound filters exclude all tones of lower frequency than 1000 Hertz.

Sound, Noise Reduction, Etc.

Measurement of Noise in Vehicles. (E. Meyer and W. Willms, Z.V.D.I., Vol. 76, No. 41, 8/10/32, pp. 983-987.) (15.20/25137 Germany.)

Exhaust noises and the noise of electric and pneumatic horns were investigated by the Barkhausen and by the Bekos and Kagan apparatus. The explosive

character of exhaust noises (especially from motor bicycles) introduces a factor of unpleasantness apart from intensity.

Determination of the Sound Spectra Produced by Aircraft in Flight. (Phys. Berichte, No. 18, 15/9/32, p. 1658.) (A new acoustic analyser, L. P. Delsasso, J. Acoustical Soc. of America, Vol. 3, No. 1, Part 1, 1931, pp. 167-178.) (15.20/25138 Germany.)

The receiver consists of a microphone and amplifier. A bifilar quadrant electrometer records the e.m.f. wave of resonance frequency, in contrast with the usual procedure of recording the current wave. The resonance frequency is controlled by the tension or inclination of the bifilar suspension.

Suppression of Noise. (G. W. C. Kaye, Engineering, Vol. 134, No. 3478, 9/9/32, pp. 314-316, and No. 3482, 7/10/32, pp. 432-434.) (15.3/25139 Great Britain.)

Paper read before British Association, York, 1/9/32—Abridged.

A useful summary is given of developments in analysis of noise and devices for its reduction or at least its exclusion from a given space.

Some numerical data of sound absorption by various materials are quoted. Applications for aeroplanes are briefly noticed.

On the Optimum Damping of Sound in Rooms. (H. Benecke, Ann. d. Phys., Vol. 15, No. 3, Nov., 1932, pp. 259-272.) (15.38/25140 Germany.)

In addition to the well-known " reverberation period " the author introduces a new term—the so-called " building up " period, during which the sound reaches approximately two-thirds of its maximum. Optimum damping is obtained when this period is about 0.06 seconds—independently of size of room.

Response during the " building up " period largely controls musical appreciation and accounts for lack of " true quality " in mechanical and electrical sound reproduction.

Passage of Sound through Small Openings. (E. Wintergerst and W. Knecht, Z.V.D.I., Vol. 76, No. 32, 6/8/32, pp. 777-779.) (1538/25141 Germany.)

Transmission of noise through walls has received considerable attention, but transmission through small openings, cracks, keyholes and cable tunnels, has been little studied. The effect of such openings may be surprisingly large, especially at low frequencies. Rules are given for reducing such transmission by suitable choice of position and shape of the orifice.

Accidents and Precautions

Quartz Bulb Fire Indicators. (G. Lockhart, Sci. Am., Vol. 147, No. 3, Sept., 1932, pp 166-167.) (16.05/25142 U.S.A.)

Fusible fire plugs have ageing defects and a considerable time lag. Quartz bulbs, filled with low freezing point liquid, and designed to burst at a given temperature, have substantially no ageing defects and about half the time lag.

Manufacturing and test operations are described and illustrated.

Aircraft, Unorthodox

Rockets with Gas Nozzles. (L. Kort, Z.F.M., Vol. 23, No. 16, 27/8/32, pp. 483-486.) (17.20/25143 Germany.)

The elementary formulæ of reaction propulsion are developed and the improvement expected from the fitting of a suitably shaped nozzle controlling the expansion of the gases is shown graphically and in numerical tables.

A few test results are tabulated.

High Altitude Flying

High Altitude Flying. (H. Barjot, L'Aéron., No. 157, June, 1932, p. 182.) (19.30/25144 France.)

French Patent No. 722857, 1931.

Two airscrews are mounted in tandem. The forward airscrew of small diameter is used alone for low altitude flying, while the after propeller of larger diameter runs free. At height a clutch is let in and the aeroplane is driven by both airscrews.

Catapults

Catapults. (P. Salmon, J.R. Aer. Soc., Vol. 36, No. 261, Sept., 1932, pp. 704-732.) (20.14/25145 Great Britain.)

The mechanical problem is stated in detail and practical solutions are illustrated by descriptions and numerous general arrangement and detail drawings of various types. Extensive numerical data are given.

Accelerations approaching 3 g. are feasible for trained pilots. In the discussion it was suggested that $\frac{3}{4}$ g. was likely to be a limit for ordinary passengers.

Lighting Accessories

New Accumulator. (Autom. Absts., Vol. 10, No. 11, Nov., 1932, p. 439; Autom. Ind., 8/10/32, p. 449.) (21.00/25146 U.S.A.)

A new alkaline accumulator combines a high e.m.f. of 1.9 volt. with less internal resistance than the Edison battery. The negative pole is of nickel and the positive pole is of conductive nickel oxide. A battery of these cells, as in use on the Irish railways, has a discharge current from 150 to 600 amperes.

Sensitive Speed Control for Electric Motors. (E. Giebe, Z. Instrum., No. 8, Aug., 1932, pp. 345-348.) (21.03/25147 Germany.)

A control mass in sensitive equilibrium under gravity, centrifugal and spring control forces, oscillates in synchronism with the motor revolutions and closes a contact, which affects the field circuit, once per revolution.

The time of contact is affected by the slightest change of speed and in turn regulates the speed to within 0.001 per cent. at 15 r.p.m.

The device is in use at the Physikalische-Technischen Reichsanstalt, Berlin.

Fog

The Transparency of Clouds and Fogs to Visible and Ultra-Red Radiation. (C. Muller, H. Theissing and H. Kiesseg, Z.V.D.I., Vol. 76, No. 39, 24/9/32, pp. 925-929.) (21.22/25148 Germany.)

Measurements of the absorption of sunlight by clouds and fogs were carried out simultaneously at wavelengths ranging from .6μ to 2.2μ by vacuum thermocouple. The sensitivity of the apparatus allowed of rapid observations during the early stages of fog formation. The ratio of distances traversed by radiations of wavelengths 0.6μ and 2.2μ for the same decrement of intensity was of the order of 20:1, which gives a measure of the greater penetrating power of ultra-red rays.

Aerodynamics and Hydrodynamics

Transference of Heat by Radiation and Convection from Vertical Hot Cylinders. (W. S. Kimball and W. J. King, Phil. Mag., Vol. 14, No. 92, Oct., 1932, pp. 570-591.) (22.0/25149 Great Britain.)

Previous semi-empirical results for steady convection currents are further discussed and formulated as " Laws," I and II.

I. The mean isotherm between body and ambient air is the locus of maximum convection velocity.

II. Half the heat is transferred within this boundary and half without it.

A further empirical result is promulgated as Law III. In the turbulent region above the critical height the rate of heat transfer is constant and equal to the mean heat transfer in the steady region below the critical height.

The so-called Langmuir film bears an analogy with the Prandtl boundary layer in hydrodynamics. The numerical results and the form of the relations are of interest, but too complex for abstracting in detail.

Apparatus for Demonstration of Superposed Flows. (C. Wieselsberger, Phys. Zeit., Vol. 34, No. 1, 1/1/33, pp. 46-47.) (22.1/25150 Germany.)

Hele-Shaw exhibited experimentally Stokes' theorem of the identity of the streamlines of a viscous film (1898) and those of a perfect fluid in two dimensions.

An extension of Hele-Shaw's results is obtained by introducing into the flow a set of sources and sinks. A streamline is formed which may be replaced by a rigid cylindrical boundary. Alternatively, any rigid cylindrical boundary can be replaced by a suitable distribution of sources and sinks.

Stability of Plane Laminar Flow of a Viscous Fluid. (H. Schlichting, Ann. d. Phys., Vol. 14, No. 8, Oct , 1932, pp. 905-936.) (22.1/25151 Germany.)

The fluid is viscous and the boundaries are parallel planes, one of which is set impulsively in uniform linear motion in its own plane. The velocity distribution in steady laminar motion is a function of the time expressible in terms of the error function and is replaced by a simple parabolic approximation which gives a close fit to the accurate expression.

A periodic disturbance is imposed on the steady flow, after the manner of Rayleigh, and a formal solution is constructed as a sum of four undetermined functions. Solutions are obtained in generalised Bessel functions and a critical value of Reynolds number is sought.

Taking water at 20°C., kinematic viscosity as 0.010 and distance of planes 10 cm., velocity of moving plane any arbitrary constant value, the author finds that the critical Reynolds number is indefinitely great at the instant of setting the plane impulsively in motion, sinks to a minimum value, 19,300, in time about 120 seconds, then increases rapidly again to an indefinitely great value for the final steady motion.

Wave Resistance. (T. H. Havelock, Proc. Roy. Soc., Vol. 138, No. A835, 1/11/32, pp. 339-348.) (22.10/25152 Great Britain.)

From the expressions for the velocity potential due to a simple source the velocity potential of a surface distribution of simple sources is found by integration over the surface. The general results are transformed and applied to express wave resistance in Bessel type integrals.

The corresponding results for a distribution of doublets is obtained by axial differentiation along the normal and the expressions for pressure distribution are developed.

The results are applied to the motion of a solid and certain semi-empirical formulæ in use are shown to be equivalent to assuming a distribution of sources.

Abacs (Nomograms) for Flow of Gases. (H. Richter, Z.V.D.I., Vol. 76, No. 13, 26/3/32, pp. 320-321.) (22.5/25153 Germany.)

An elaborate semi-empirical formula has been established for expressing the flow of a gas through a nozzle in terms of initial pressure, pressure at the throat, ratio of inlet to throat section, compressibility, density, etc.

Three Abacs are reproduced which permit rapid numerical evolution of the formula for specified values of the variables.

Six references.

Materials, Elasticity and Plasticity

Fatigue Strength and Crystal Orientation. (W. Fahrenhorst, K. Matthaes and E. Schmid, Z.V.D.I., Vol. 76, No. 33, 13/8/32, pp. 797-799.) (23.10/25154 Germany.)

Experiments on single crystals showed a definite relation between crystal orientation and fatigue strength. Experiments on electrolytic copper strip, a crystalline conglomerate, gave similar results. Under periodic loads an initial improvement in the mechanical properties was followed by breakdown of the crystal lattice structure, with rapid concomitant deterioration, which was influenced markedly by the orientation of the crystals.

Buckling Strength of Columns. (W. R. Osgood, Bur. Stan. J. Res., Vol. 9, No. 4, Oct., 1932, pp. 571-582.) (23.30/25155 U.S.A.)

Euler formula for buckling has been extended to cases where part of the material is beyond the yield point by a number of authors. Priority is assigned to A. Considère (1889), F. Engesser and F. Jasinski. Reference is made to independent work by v. Karman, Southwell and others.

The mathematical analysis is developed as far as is possible without a prescribed section and yield point.

Numerical cases are reduced and exhibited graphically; the working formula of a bridge building firm is reduced and the stress strain diagram is exhibited, which would make the formula accurate.

Applications of the Polar Diagram. (E. H. Atkin, Flight, Vol. 24, No. 35, 26/8/32, pp. 802e-802h; No. 40, 30/9/32, pp. 918c-918g; No. 44, 27/10/32, pp. 1008e-1008g.) (23.40/25156 Great Britain.)

The method of representing the variation of moment along the span of a beam in polar co-ordinates devised by H. B. Howard, R. & M. 1233, 1928, is applied to a number of examples The saving in time and labour is evident and the accuracy is, in general, amply sufficient for engineering calculations, though critical cases may require analytical investigation.

Mechanical Tests of Aircraft Structural Materials. (I. J. Gerard, J.R. Aer. Soc., Vol. 36, No. 261, Sept., 1932, pp. 673-703.) (23.50/25157 Great Britain.)

The application of compression tests to determine the buckling load of thin steel is illustrated by photographs and diagrams of the apparatus. The tensile strain stress diagram is considered and two typical curves are reproduced to illustrate the ranges into which it may be divided. Two experimental curves show the effect of temperature of oil and air hardening on the range of the strain stress diagram. A brief reference is made to corrosion. The application of the knowledge thus obtained as the basis of a mathematical theory of elastic structures with modifications for plastic yield is extremely difficult beyond the first approximations. Direct test under loading reasonably equivalent to flight conditions requires somewhat elaborate apparatus.

The author gives a full description of a test plant at R.A.E., in which the loads are applied by hydraulic rams and a system of linkages and levers distributing the forces over the frame of a large wing. The rapidity with which improved results are obtained is considered to justify the cost very fully.

Other methods and apparatus for testing large beams, girders, monocoque bodies, hulls, etc., are discussed and illustrated. A lengthy discussion follows which, with the reply, covers a wide range of problems in this highly specialised branch of aeronautical engineering.

Seven references.

Miscellaneous

Electrical Discharge in Compressed Gases and Liquid CO_2. (O. Zeier, Ann. d. Phys., Vol. 14, No. 4, Aug., 1932, p. 415.) (0/25158 Germany.)

Experiments were carried out in air, nitrogen and CO_2 at pressures up to 120 atmospheres. The discharge voltage between spherical electrodes is a function of the product of gas pressure and electrode distance (Pashen's Law) up to a certain pressure lying between 30 and 50 atmospheres, beyond which the rate of increase of the discharge voltage falls off. These changes are explained by emission of electrons and the development of body charges.

Experiments with liquid CO_2 at high pressure yielded similar results to that of air at the same pressure.

CORRESPONDENCE

The Editor, JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

3rd March, 1933.

Sir,—I notice that in Capt. Norman Macmillan's paper on "Air Navigation," under the heading of "Terminology," the length of the kilometre is stated to be the 1/10,000 part of the quadrant. In the interests of accuracy may I point out that it is not.

A kilometre is, of course, 1,000 metres and the metre was originally intended to be equal to the one ten-millionth part of the length of the meridian through Paris from Pole to Equator. Actually, something went wrong with the measurements or calculations, with the result that the metre is now an arbitrary standard, and is defined as the distance apart of two lines on a platinum-iridium bar called the "International Prototype Metre," certain specified temperature conditions being adhered to.

Yours faithfully,

W. O. MANNING, F.R.Ae.S.

REVIEWS

High-Speed Diesel Engines

By Arthur W. Judge. Chapman & Hall, 10/6.

This book contains a large amount of information relating to high-speed compression ignition engines which Mr. Judge has succeeded in obtaining from manufacturers of such engines. It is well illustrated, contains a large number of small scale section drawings, and those interested will find a large amount of information on the progress of these engines arranged in an accessible and convenient form. There are also chapters on elementary theory, fuel ignition systems, etc.

Readers of this Journal will be more interested in the chapter on compression ignition engines intended for aircraft. This chapter is disfigured by details of an extraordinary trial between two aircraft, stated to be of similar design, powered with compression ignition and petrol engines respectively, in which the compression ignition engined aircraft is made out to be much the better. No references are given to enable the data to be checked, but it is unbelievable that in two aircraft of similar design driven by engines of similar power that the top speed of one would be 116.5 miles an hour, and of the other 103.2 miles an hour, unless there was an important difference in the head resistance of the two. Needless to say, the compression ignition engined machine is the faster. Its climbing speed is also better, as might have been expected, in view of the fact that its weight is 141lbs. less.

Mr. Judge thinks that one of the reasons for this is the greater cylinder capacity of the compression ignition engine, which, it seems, has a favourable influence apart from the power developed.

He explains the better climb of the compression ignition engine by stating that if the quantity of fuel required to carburate half the air taken in to the engine is injected at ground level, the lever regulating this need not be touched until the machine reaches 18,000ft., where the density is about half that at ground level. Apparently he thinks a compression ignition engine can use all the air drawn in at this altitude, although it cannot use more than about 80 per cent. at ground level.

Actually both petrol and compression ignition engines are on a par in this respect; in both cases it is necessary to regulate the fuel by hand, in proportion to the weight of air taken into the cylinder, as the aeroplane climbs.

Mr. Judge performs a useful service in collecting and publishing data. It is unfortunate that he allows himself to comment on matters which he has obviously not studied.

Simplified Aerial Navigation

By J. A. McMullen. Chas. Griffin, London, 1933. 5/-.

This is an excellent little book which deals in a clear and comprehensive way with Aerial Navigation by Dead Reckoning. Compass deviations are explained in the opening chapters and the methods of adjusting these instruments and of using protractors are fully described. The author deals with the parallelogram of forces, explains how courses are set out and devotes a special chapter to navigation for the lone pilot.

This is a most useful work for those commencing the study of aerial navigation and can be thoroughly recommended to private owners, who will find in it sufficient information to enable them to find their way about. It would be improved by devoting a little more space to maps; such matters as contour lines or the mauve lines indicating international air routes, which latter are not found on the older maps, deserve consideration in connection with map reading.

Lubricating and Allied Oils

By Elliott A. Evans, F.C.S., M.I.P.T. Chapman & Hall, 9/6.

Mr. Evans is Chief Chemist to Messrs. C. C. Wakefield & Co., Ltd., and this book, as might be expected, contains a large amount of information on oils. It starts with some interesting information on the history of the subject, contains chapters on Physical Tests, Chemical Tests, Decomposition of Petroleum, Oleography, selection of Lubricants, etc.

As might be expected, much of the information is of more interest to the chemist rather than to the engineer, but the latter will be all the better for full information on such tests as viscosity tests and flash point as he will be better able to judge the value of such tests on the oils that he is using. Chemical tests are of less direct interest, but they are of importance when such matters as studying may cause trouble, or in connection with deposits in the cylinders or on the pistons of internal combustion engines, etc. The only question that will arise is how far the working conditions can be considered as being represented in the laboratory tests.

The engineer will naturally turn with interest to the chapters on the employment of oil. These chapters are, perhaps unavoidably, less informative than might be hoped. The reason seems to be that lubrication is almost entirely an experimental science and that no satisfactory theory as to why one chemical liquid lubricates and why another does not has ever been developed. That it has something to do with the shape and size of the molecule seems certain, but the exact connection has yet to be traced. Viscosity is of unquestionable importance, but many viscous liquids are useless as lubricants.

Oils for aero engines are discussed in a short paragraph, and it is clear that the author prefers an oil containing castor for this purpose owing to the high loads on the bearings and the great reliability required. His remark that a plain mineral oil causes more dirt in an engine than castor oil is not consistent with earlier experience. Those who have had to run them will remember the caking caused by castor oil in engines of the Gnome type. Mineral oils have been extensively used in aero engines in America, with satisfactory results. They have the advantage of being cheaper than oils containing castor and are more easily obtainable in out of the way places. It is inconvenient to be tied to a particular brand of oil now that aeroplanes can fly to all parts of the world.

The book is one that should be read by all users of lubricants.

The 554th Lecture read before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Fifth Meeting, First Half, 68th Session

The Fifth Meeting of the first half of the 68th Session of the Royal Aeronautical Society was held in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, November 10th, 1932. In the chair, Mr. C. R Fairey, M.B.E., F.R.Ae.S., President of the Society.

The President: Before calling upon Mr. Hollis Williams to read his paper, the Society welcomed that evening a very distinguished overseas visitor, Mr. Edward P. Warner, who had been a member of the Society for a great many years, though this was the first occasion on which he had attended one of the meetings. Mr. Warner was formerly aeronautics professor in Massachusetts, he had done distinguished work in the American Navy, and he was to-day the editor of "Aviation," and a distinguished figure in the aeronautical world.

A slight change had been made during this session in the procedure as to the chairmanship of the meetings. The President was not taking the chair at every meeting, but the chairman was chosen either from his knowledge of the subject or of the lecturer. His own qualifications that evening came under the second heading. He had great pleasure in introducing Mr. Hollis Williams. Mr. Williams left school before he was eighteen to join the Royal Flying Corps, which he left in 1919 to become an aeronautical engineer, taking his degree in 1922. He would not take the audience piece by piece through his career, but he was to-day the chief designer of his (the speaker's) company. He first attracted attention for the reason that he was one of the few engineers who owned and flew his own machine before such aircraft as the Moth and others were available to the ordinary private individual.

After the present meeting he and Mr. Williams were going down to Cranwell, weather permitting, to witness the start of what it was hoped would be a flight bringing a new record to this country. If the flight was successful the credit would, of course, go to those gallant officers who would pilot the machine across the Sahara, and the worst parts of Africa, and take what chance of weather 60 hours of flying might bring them. But the greater part of the technical credit for what the machine had already accomplished went to Mr. Hollis Williams.

AIRSCREW DESIGN

BY

D. L. HOLLIS WILLIAMS, B.Sc., A.F.R.Ae.S.

Introduction

From time to time alternative methods of generating thrust have been proposed, but for a variety of reasons early promise has failed to mature and the airscrew remains without an important challenger as the best available means of impelling an aircraft through the air.

As the most efficient means by which the rotational energy of an engine can be converted to a translational force, the design therefore calls for special consideration, as an otherwise highly efficient engine and aircraft may have but an indifferent performance unless the airscrew is suited to their particular requirements.

Selecting the form to be taken by the present paper has occasioned some uncertainty due to the very wide field covered by the title, "Airscrew Design."

After consideration of the various methods of treatment and as this subject has not occurred recently in the proceedings, it has been decided to make a brief review of the present position of design, dealing only with such parts as are of interest from the engineering point of view and it is hoped that the result will be to present this aspect of the subject in an interesting light to the members of the Society.

Due to the restricted length of the paper some cases which require specialised treatment have had to be omitted, but the outline of the problem, corresponding to the engineer's outlook after continued application of design methods to all classes of airscrews, it is hoped will present a useful picture of the workings of the process defined mathematically elsewhere.

Discussion of practical research has been omitted and reference made only to the methods of testing because of the difficulties of obtaining full-scale airscrew data in flight with sufficient precision to be advanced under the hall mark of scientific evidence, especially as engine output and aircraft characteristics have often to be separated out. Moreover, various Government research establishments are well equipped to deal with this side of the problems.

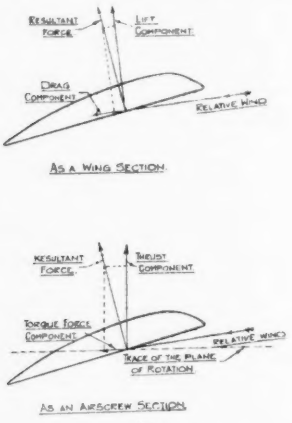

FIG. 1.

Wing aerofoil section showing lift and drag components. Airscrew aerofoil section showing thrust and torque.

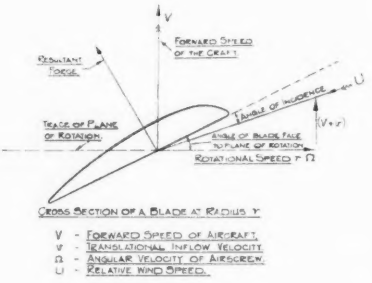
V
FORWARD SPEED OF THE CRAFT
RESULTANT FORCE
TRACE OF PLANE OF ROTATION
ANGLE OF BLADE TALE TO PLANE OF ROTATION
ROTATIONAL SPEED = Ω
CROSS SECTION OF A BLADE AT RADIUS r
V - FORWARD SPEED OF AIRCRAFT.
v - TRANSLATIONAL INFLOW VELOCITY.
Ω - ANGULAR VELOCITY OF AIRSCREW.
U - RELATIVE WIND SPEED.

FIG. 2.

Distribution of component velocities and resultant force.

General Description of Airscrew Action

The forces set up on an aeroplane wing in steady level flight are generally understood and the type of air forces on an airscrew blade is somewhat similar. It is clear that when a wing is driven level in a straight line at steady speed the driving force equals the resistance and the lift equals the weight supported. If the driving power be increased the wing can then follow one of two steady motions: Either it can decrease its incidence and continue on the level at higher speed, or it can climb. If now the flight path is a spiral instead of a straight line we have at once a rough representation of airscrew action. In the example of climbing flight the analogy is obtained when one considers the wing as a portion of a blade and constrained with its neighbouring elements to a driving shaft. The force previously making it climb now appears as a thrust on the shaft and the drag appears as a resistance to rotation which becomes the torque when associated with the radius.

This outline of propeller action refers to the state of working with which we are chiefly concerned within the limits of the present paper. The airscrew can also work as a brake and as a windmill when engine power is shut off, but the airscrew characteristics to meet these conditions are not a basis of propeller design.

The Principal Features of the Airflow

For some few diameters length ahead of the advancing propeller the air is aware of the approach and is in fact attracted towards the airscrew. On arrival this air is attacked by the blades which impart a rotation to the outflow and a train of phenomena ensues substantially as associated with wing aerofoils. In front of the airscrew the pressure falls and the air velocity rises. On passing through the airscrew disc the inflowing air receives, more or less impulsively, a further and considerably larger instalment of energy, and the resultant fluid motion is then represented by an energy system in which the total rate of change of momentum in the air is reacted by the air forces on the blades. Immediately behind the disc the pressure rises but falls again as pressure energy appears as kinetic energy. Eventually this energy is dissipated by fluid friction as the wake trails downstream.

The first portion of the slipstream may be imagined as part of a right circular cone, the base being coincident with the airscrew disc. The surface of the cone represents the bounding surface of the slipstream and is a vortex sheath fed by trailing vortices running off the blades. The vorticity in this sheath will in turn balance the circulation of air about the longitudinal axis of the slipstream; this circulation amounts to a central vortex which can have a solid stationary core as, for example, a fuselage or engine nacelle or, for some " pusher " airscrews, a specially built-up spinner. In the immediate neighbourhood of the airscrew the energy contained in the rotating mass of the slipstream is directly proportioned by the engine power used to overcome the torque and similarly the energy represented by the added linear velocity in the slipstream may be referred to the thrust. Radial components of velocity in the first portion at least of the slipstream, are very small for normal propeller action. To cope with the definite fluctuations with time of both linear and rotational velocity, design theory assumes steady mean values for these periodic functions and in this respect is in line with a procedure common in practical considerations of other fluid motions met with in aeronautics. Similarly only mean values of pressure are considered and are likewise assumed to have constant values at equal radii at any given cross section of the slipstream. This assumption leads to the idea of average streamlines disposing themselves about a central axis at appropriate radii to form a series of concentric stream tubes, which is the simplest way of visualising the energy distribution and structure of the slipstream.

Remarks on Design Theories

Broadly speaking, the theory of the working airscrew has been satisfactorily established for some years on two or three primary hypotheses. The analogy of the slipstream to a jet of fluid was the starting point of the momentum theory, and the similarity of an airscrew blade to an aeroplane wing was the source of a second theory. A later theory satisfies both points of view and contemplates the main physical features of the fluid motion. Although complete theoretical prediction of the real fluid motion remains a somewhat remote possibility the velocity field around the airscrew has been calculated for the simpler case* of the perfect or inviscid and incompressible fluid, and in this connection it is fortunate that the flow pattern for an airscrew in a perfect fluid approaches

* " On the Vortex Theory of Screw Propellers." S. Goldstein. Proc. Roy. Soc. A., Vol 123, 1929.

nearer to the real average flow than in other important parallels. It is seen, therefore, that there is some logical explanation of the fact that design procedure has remained empirical, to be justified on somewhat general grounds and the continued success of new designs despite some broad approximations.

General design theory has been demonstrated to be satisfactory over a wide range; the recent Schneider Trophy contests and finally the speed record flights, for example, provided a hitherto unfamiliar region and airscrews based on common theory satisfactorily reproduced design specifications in full flight without recourse to any unusual adjustments of pitch following trials.

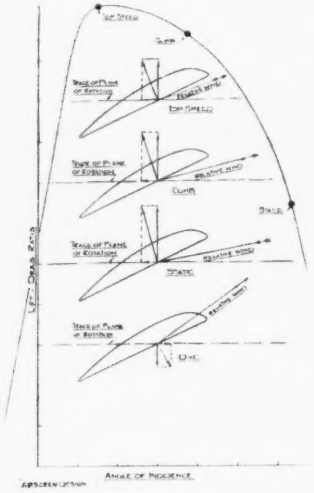

FIG. 3.

Airscrew sections: incidence thrust and torque—Top speed, climb, static, dive.

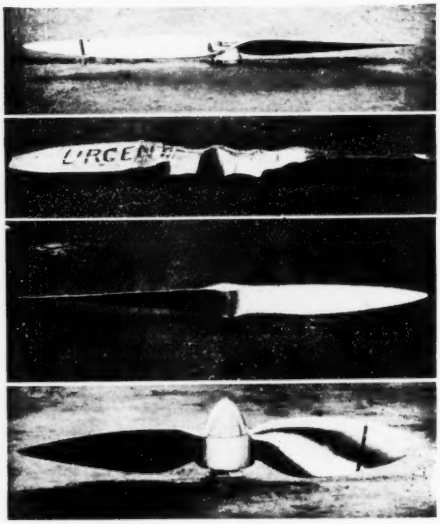

FIG. 4.

Three airscrews and one blank lying on the ground. Top, "D" type. Next down, blank "R" type. Next bottom, early "R" type. Bottom, racing airscrew.

Design Methods

Design methods fall readily into two main divisions devoted respectively to aerodynamics and to strength calculations. On the aerodynamic side methods in common use again divide under two heads; on the one side are tabular methods dealing explicitly with a number of elementary lengths of blade, integrating the various characteristics over the whole radius to arrive at the performance of the airscrew; on the other side are analytical methods which start from a consideration of a single element of blade somewhere out along the radius and proceed to the performance of the complete airscrew by the aid of an integration factor. These factors are known to depend on several variables and chiefly upon a group of engine characteristics of which certain periods of vibration may be one factor. This is seen to be a stage at which practical experience does not follow the anticipations of accepted theory. The corresponding empirical corrections are made in the tabular methods in a different manner, and commonly by selecting an airscrew for the value of the ratio of its pitch and diameter.

Choice of method is seen to be a matter of some expediency. The analytical method is perhaps less in use in this country and it may be mentioned that, when backed by sufficient experience, it offers advantages of economy in computation.

The degree of accuracy of any design is dependent upon such factors as the velocity distribution across the airscrew disc, which is affected by the shape of any body in close proximity, and on knowledge of scale effect and interference, and in practice these are often covered by an assumption as, for example, in the tabular methods by assuming a constant increment ratio for linear inflow at all radii. Such factors and the effects of engine vibration are seen to be determinate only by full-scale wind tunnel tests, but are, however, amenable to treatment by an empirical correction factor following full-scale trials, and in this respect the type of airscrew that can be repitched at once scores.

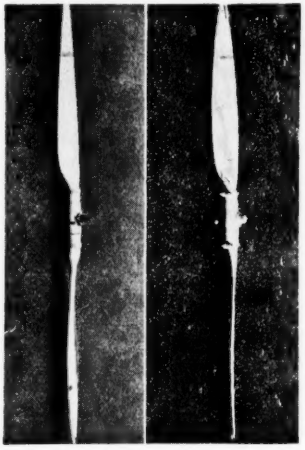

FIG. 5.
Two adjustable airscrews.

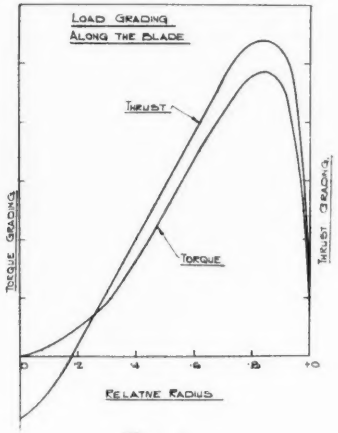

FIG. 6.
Curves of thrust and torque grading.

Apart from attainable accuracy, the degree of approximation permissible in airscrew calculations depends, of course, on the penalties following incorrect design; on the other hand, the saving of time due to such methods is important in commercial engineering. Adjustable types and thin metal airscrews may be repitched by retwisting in the event of an incorrect approximation, whereas for wooden or stiff metal blades a higher degree of accuracy is required, as incorrect performance cannot be remedied by any convenient adjustment.

The analytical method proceeds from knowledge of the aerodynamic characteristics of the typical aerofoil section and by means of an integration factor, blade width and incidence at the particular radius are arrived at. The integration factor, which may be said to be the ratio of actual blade loading to a uniform blade loading, is seen to include implicitly the effects of the degree of approximation when the actual loading is found from practical tests. It follows that if standard blade shapes embodying a uniform change of section are normally used, the integration factors can be determined accurately as the result of experience.

Having determined blade width at a selected radius, a standard-shaped blade is drawn round this particular dimension, followed by a suitable grading of

sections. The blade is then given a helical twist producing a constant pitch for the blade face angles for conditions of approximately constant velocity distribution. Alternatively, a non-helical twist may be required to account for known conditions of velocity distribution across the airscrew disc. The initial stage of the design is then completed.

The performance of the airscrew is arrived at by considering the typical section at different incidences in turn, from top speed to static conditions, and a series of airscrew characteristic curves can be obtained and can be used with facility for all performance calculations, both in full throttle and in throttled flight. Here, again, use of the convenient integrating factor is necessary and its value to a first approximation is taken as constant throughout the speed range, and this is found in fact to be very nearly true.

This method has been used with success over a very wide range of designs, including thick and thin metal airscrews and wooden airscrews, and considering the number of new designs produced, the number of adjustments which occasionally have to be made after flight tests represents a very low percentage.

The full-scale wind tunnel has been employed in America in an extensive research, using a series of standard-shaped airscrews working on various combinations of engine and body. The very full sets of characteristics compiled for different families of airscrews under exact working conditions tend to substitute a process of selection for that of airscrew design.

We have, in this country, not yet had time to digest and appreciate the wealth of scientific data thus made available, but it is probable that there is sufficient information available to round off airscrew theories.

Returning to the process of design: It has now to be checked for strength, calculations being relied upon for variations of known types of blade.

Available methods range from a relatively simple theory that ignores all deflections of the blade to a precise theory[1] that accounts for the strains due to bending. Various degrees of approximation may be applied when feasible, and are usually concerned with the root portion of the blade. Experience has shown that one or other of these methods leads to satisfactory design for strength.

An interesting point in contrast with considerations of aircraft wing strength is the neglect of the torsional components of forces tending to twist an airscrew blade. Torsional loads can arise from two sources; firstly by the shift of the centre of air pressure along the chord as the incidence varies, and secondly by centrifugal force acting on the expanse of blade and tending to straighten it out parallel to the plane of rotation. Experience has demonstrated, however, that the torsional strains are small and that strength determinations accounting for the blade as a cantilever beam in tension, loaded by the thrust and lateral forces and by the loads and bending moments due to centrifugal force, lead to completely satisfactory estimates of the strength of each design.

The reliability of the results of strength calculations is subject, however, to the unconsidered periodicity of the loads not setting up subsidiary stresses in the fatigue range of the material. These alternating stresses may occur due to variations of engine torque (the fewer the cylinders the worse the torque variation), blade flutter, or simply excessive vibration due to engine or airscrew being out of balance.

Because of the great difficulty of computing the effect of these periodic forces, all essentially new airscrew designs are subjected to a centrifugal overload and to engine endurance tests, which procedure, however, makes introduction of new types somewhat slow and expensive.

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* "The Equilibrium of Loaded Impeller Blades, with special reference to the Strength of Thin Metal Airscrews." By the late P. A. Ralli. Journal R.Ae.S., February, 1931.

Design Problems and Procedure

The problem of design reduces to the requirement that the airscrew shall be so proportioned as to size, distribution of aerofoil sections and incidence and number of blades, that the translational component of the energy in the slipstream is a maximum.

A large family of airscrews can be designed which will utilise the permissible engine speed range, but of these one will give the best top speed, others the best climb, or range, or take-off, or initial climb.

The one which gives the best speed will not give the best performance elsewhere in the speed range. In general, the larger diameters are required to develop maximum performance at the slower speeds. The good-all-round airscrew is to some extent a compromise bearing on all these points.

It is now usual for an airscrew to have to comply with dual performance requirements; namely, to permit maximum engine r.p.m. at top level speed and " normal " engine speed at the best climbing speed. This dual requirement narrows the field for selection, and if the diameter is fixed by other considerations, then, out of a particular family, the only member which will comply can be conveniently determined by a simultaneous solution in the analytical method.

As has already been mentioned, given a completely free selection, the field of design is very large—due to the number of variables—and requires an extensive investigation to determine the best selection, but usually in practice prior

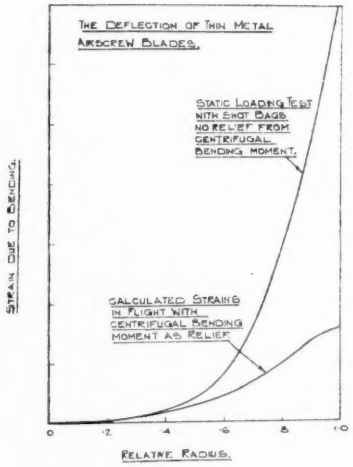


FIG. 7.

Curves of deflection for thin metal airscrew.

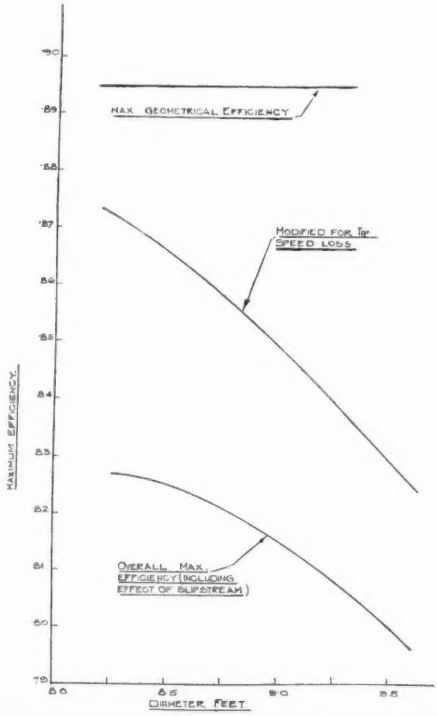


FIG. 8.

Curves of component efficiencies.

selection is made of engine gear ratio and the diameter is commonly limited by chassis, float or fuselage clearance, which considerably simplifies the work.

At this juncture it is convenient to distinguish the component efficiencies that enter into airscrew design.

The initial figure for efficiency appearing in airscrew performance calculations may be referred to as the geometric efficiency, as it depends only on the angle of the relative wind to the plane of rotation and on the angle subtended by the resultant air force with the direction of the relative wind. Before useful application, however, this efficiency will be modified to account for extra drag on the craft caused by the higher speed of the slipstream and further by an allowance for any losses caused by excessive speed of the blade tips. Extra drag caused by the slipstream depends on the intensity of the wake and on the obstacles it meets in making its escape. The intensity behind a large diameter airscrew is seen to be less than behind one of smaller diameter working to the same design specification. On the other hand, more structure may be immersed in the slipstream behind the larger diameter. Accurate computation is possible, therefore, only from a knowledge of the external form of the aircraft and the disposition of the airscrew.

Losses due to high tip speed are associated with the compressibility of the air, and commonly occur when the speed of a blade tip reaches speeds of the order of the velocity of sound in air. As yet no theoretical interpretation in a form convenient for application to general design work is available. On the empirical side, however, the drop in efficiency has been measured over a considerable range and has been found to depend to some extent on the type of aerofoil sections near the tip of the blade and also on their rate of advance per revolution.

The Aerofoil

Looking at the problem in greater detail, the effect of several variables will be traced. From the standpoint that an aerofoil operates at its maximum efficiency when at the incidence corresponding to the maximum value of the ratio of lift to drag, the fundamental design problem may be said normally to resolve itself into arranging for all sections of the blade to work as near as possible to their maximum efficiencies at top speed in level flight. In some cases where the slower speed condition cannot be satisfied simultaneously by this arrangement, the aerofoil sections are set at lower incidence, and so work below the peak of the lift-drag ratio curve at maximum level speed, but produce an improved performance at the lower end of the speed range.

Despite the limitations just described, it is almost always feasible to choose aerofoil sections and incidences leading to high efficiencies for the design specification; or, in other words, the design selected is not very far removed from the best possible top speed airscrew.

In a previous paragraph the similarity noted between a wing and a length of airscrew blade also applies to their aerofoil sections. For given conditions of wing loading and power loading the speed range of an aircraft depends on the " lift life " of the wing aerofoil sections; that is, the amount of incidence variation available between zero lift and the maximum value. An airscrew's characteristics are determined in an analogous way by the distribution of aerofoil sections along the blade, since each blade section—like the wing—works through a range of incidence.

The ratio $V/\pi nD$ will be recognised from Fig. 2 as the tangent of the angle between the relative wind direction and the plane of rotation, neglecting the inflow velocity. Therefore, the more usual term V/nD is related to the direction of the relative wind. The greater the value of the ratio V/nD at top speed in level flight the steeper the incidence of the wind, and of necessity the steeper the blade face angle, in order to present the aerofoil sections at

suitable angles of incidence. It was noted earlier that this incidence at top speed will, on many designs, be selected to correspond with the maximum lift-drag ratio of the aerofoil section concerned and will, therefore, be a small positive value. Now it follows from the remarks on V/nD that at slow speeds, the apparent wind making only a small angle with the plane of rotation, the incidence of the aerofoil sections will be proportionately large on a fixed-pitch blade. On airscrews for aircraft with a large speed range, for example, variation in incidence may exceed the useful range of some or all of the sections, which explains the phenomenon of a " stalled airscrew."

Clearly, it is desirable for the range of incidence occurring on any airscrew of fixed pitch to fall within the useful incidence range of its aerofoil sections. By virtue of their increased range, it is easier to accomplish this with thick than with thin sections, but except due to unwise choice of diameter and gear ratio the problem does not usually arise below forward speeds of about 200 m.p.h. When this problem does appear on slower machines it is usually the result of restricted diameter or an unnecessarily low gear.

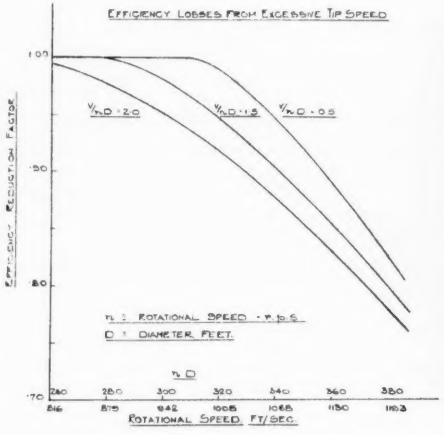


FIG. 9.

Curves of efficiency losses from excessive tip speed.

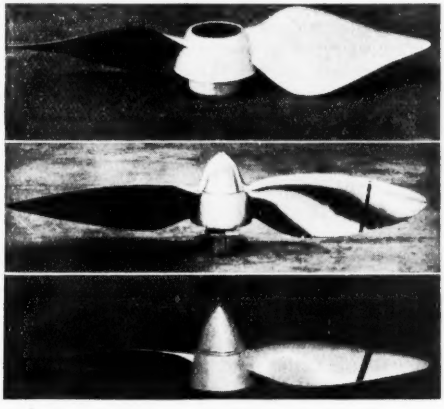


FIG. 10.

Three photos of 1929 racing airscrews in descending order of blade width. "Ace of Spades" at top of slide.

In general, it may be said that the thicker the blade aerofoil section the better it is equipped to deal with all-round performance; but, on the other hand, the thin aerofoil develops a higher ratio of lift to drag at top speed, and if a blade develops more thrust for a given power it follows that efficiency is correspondingly larger, and this explains a difference between thick wood or metal airscrews and thin metal types.

Diameter and Gear Ratio

To follow the effects of the variables—diameter and rotational speed—it is convenient to assume a range of diameters and gear ratios to be available and to follow selection of design conditions for a single specification.

One method of tackling this problem is to decide on the highest tip speed suitable for the class of aircraft. Theoretically several factors come into this, but the decision may be supposed as based on data from tests in a full-scale

wind tunnel, as such data is now available and is in fair agreement with experience. Having fixed the peripheral speed of the blade tips, the product of maximum rotational speed and diameter is also fixed and hence the corresponding value of V/nD is known and a family of airscrews complying with these conditions may be said to work over a common range of incidence, so that selection might be expected to fall on the lightest. In practice, however, it would be found that the airscrews of small diameter would, in addition to handicapping slow speed performance, cause undue concentration of the slipstream with the consequent extra drag, and would be subject to heavier interference by the body. On the other hand, the combination of very large diameter and low gear ratio would be rejected on the score of weight on all but very large aircraft, and possibly also because of ground clearance. It may be assumed that usually the practicable selection falls on an intermediate combination.

It can be shown for a given design specification that for an accepted tip speed the theoretical or geometric efficiency depends only on the diameter, and improves as diameter increases, but it has been seen that practical considerations tend to limit the growth of diameter.

The diameter of an airscrew is also influenced by the speed at which it has to develop its maximum efficiency, as the available engine power is absorbed by accelerating a given mass of air per unit time. It follows, therefore, that for equal power output the optimum diameter of a high-speed airscrew is less than that of a slow forward speed airscrew.

Having selected gear ratio and diameter, a series of solutions is possible for blade width and incidence, and the best combination will be determined following a survey of all the design conditions. Thus dual requirements as to maximum speed and climb will frequently point to the solution. If speed alone is the objective, then blade sections will be set for maximum efficiency as already described. When take-off and climb are specially important the section will be pitched so as to work at relatively high efficiencies at the lower speeds, which entails some sacrifice of high speed performance.

Blade Width

Blade width will be seen to vary simultaneously with diameter on any one design, as decrease of diameter will be compensated by increased blade width rather than by increased incidence at the design conditions; because, as has been seen, the whole of the useful incidence range may be required to avoid stalling of the blades at low speeds, and, what is usually more important, the best efficiency is probably required at the top speed condition, and blade incidence is thus, in effect, predetermined. Where blade width becomes inconveniently large, whether on the score of interference effects or manufacturing difficulties, the solution is frequently to subdivide into three or four blades at some expense to weight—the airscrew performance depending only on the total blade width and not on the number of blades.

It is seen from the foregoing remarks that the field for selection is large, but usually in practice a specified engine gear ratio and/or limited ground clearance, forces a selection of diameter. There is then a family of airscrews that complies with the top speed specification, in spite of different aerofoil sections, blade widths and incidences, although the members will differ at all other points in the performance range.

The Influence of Airscrew Design on the Performance of Aircraft

The effects of the several variables of design have been explained and it has been implied that the performance of an aircraft can be considerably affected by a change of airscrew. The practical solutions for various cases of extreme airscrew performance will now be illustrated.

High Speed

As an ideal the design of a high speed racing airscrew forms the simplest case involving no compromise, but in practice, in recent Schneider Trophy seasons, for example, design conditions were found to be so extreme that it was necessary to study take-off as well as maximum speed.

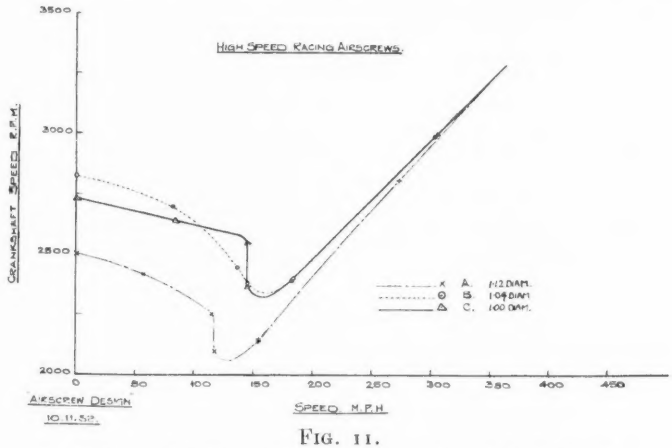


FIG. 11.

High-speed racing airscrew curve of crankshaft speed.

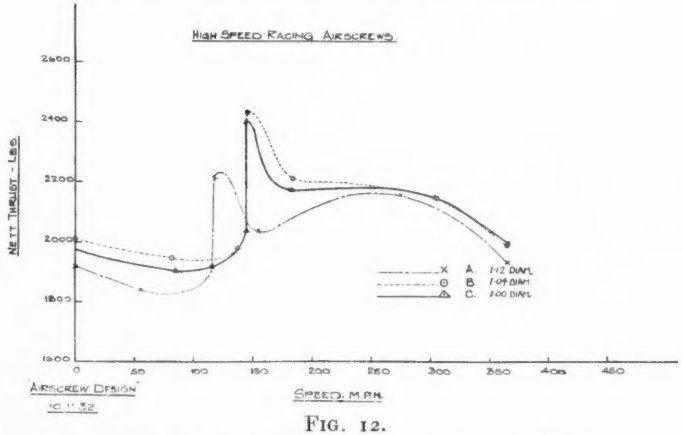


FIG. 12.

High-speed racing airscrew curve for nett thrust.

In the last Schneider Trophy season of 1930 the only gear ratio available was not low enough to accommodate the best possible airscrew, but the optimum diameter calculated for the available gear was 8ft. 6in., which choice was, incidentally, later confirmed by wind tunnel tests at the N.P.L. A feature of this design was the narrow rotational speed range between static conditions and top level speed, which is very important, as during the run to take-off the airscrew is completely stalled, being at an average incidence of about 24°, and the thrust available depends mainly on the engine power developed.

The thrust developed by these airscrews during the run on the water was of the order of 1,900lbs. only, or about equal to that of a normal seaplane using about one-fifth of the power. It is usual for racing seaplanes to be only partially controllable until a considerable speed has been attained and in the early stages of the run to take-off it has been common to experience a swing. With the smallest diameters used in the last racing season this swing was found to be excessive for the available directional control and was cured by a return to larger diameters as being the easier solution. The yawing was due to the swirl of the very intense slipstream from the small diameters having caused a critical airflow over the fin and rudder.

Another point of interest observed on these airscrews was the absence of severe losses of efficiency when the resultant peripheral speed of the blade tips slightly exceeded the speed of sound in air. Previously the airscrew sections had been modified to this end, not only by choosing the thinnest possible consistent with strength requirements, but also by particular attention to the profile of the portion near the leading edge. Overall efficiencies between 80 and 85 per cent. were measured on the airscrews used during the season.

Take-off and Initial Climb

Slow speed performance is normally favoured by large diameter with broad blades, working at very small incidence at top speed, that is, at incidences less than the optima for maximum efficiency. The limit to which this procedure may be carried is quickly reached on metal airscrews as the weight becomes prohibitive. An alternative method is to design for a lower speed than the normal maximum of the aircraft, so that throttling is necessary at top speed to avoid over-running the engine.

In these ways good improvement in take-off or climb can be obtained and they are used for interceptor fighters and for the take-off and initial climb of very heavily laden craft. It is also a precaution in emergency to use an airscrew of reduced pitch to increase the margin of safety when taking-off from restricted areas.

However, for normal usage, it is illegal to exceed " normal " engine r.p.m. at best climbing speed or to use an airscrew which requires the engine to be throttled at top level speed. This latter requirement is illogical and practically impossible to enforce, especially with adjustable or variable pitch airscrews.

The outstanding example of the necessity to favour take-off is the extreme long range aircraft, on which the airscrew of optimum design for average economical cruising conditions would never get the load off the ground. The Fairey Long Range Monoplane starts on its record attempt at a wing loading of about 20lbs. per square foot and a power loading of 30lbs. per b.h.p. The airscrew, 13ft. 9ins. in diameter, working on a gear ratio of .531 generates a starting thrust of nearly 3,000lbs., running at just above " normal " r.p.m. and achieves maximum permissible r.p.m. at its best climbing speed off the ground. The cruising efficiency under these circumstances is low and the effect of high values of r.p.m. during the cruising has an unfavourable effect on specific fuel consumption.

The design features of an airscrew for operation at great height are very similar to those required to favour take-off and initial climb.

Range

The most efficient airscrew design for economical cruising (which, paradoxically, cannot be complied with by an airscrew of fixed pitch on the Long Range Monoplane) is one which holds down engine speed. The effect, apart from small variations of airscrew efficiency, is to benefit specific fuel consumption because of reduced frictional losses in the engine. The limit to this arrangement

is reached when the throttle is fully open at the engine speed required. If carried too far it is possible to exceed engine type test conditions and it is therefore illegal to use an airscrew of so high a pitch that in level flight at full throttle the engine speed is less than the defined normal value.

It needs no further illustration than these examples to indicate that there is a definite need for the variable pitch airscrew, at least for extreme performance and the interesting study of the advantages and difficulties of this line of airscrew development will now be outlined.

General Notes on Variable Pitch Airscrews

The variable pitch airscrew presents a difficult mechanical problem, as is evidenced by the few examples in every-day use, but judging from the number of schemes produced it might be supposed to be a very desirable aid to aircraft performance.

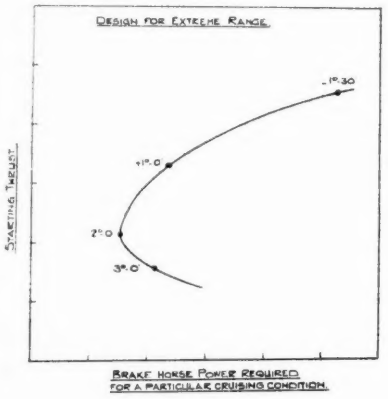


FIG. 13.

Curve design for extreme range starting thrust.

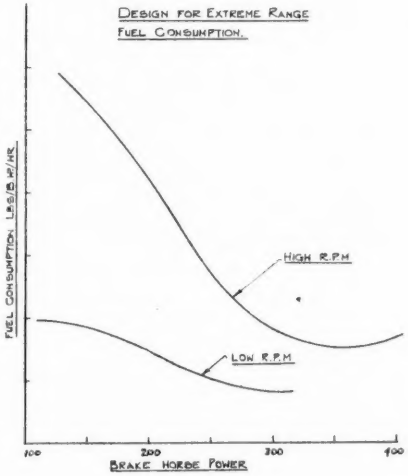


FIG. 14.

Design for extreme range consumption.

When the problem is examined in detail, however, it is found that in many cases the variable pitch airscrew does not warrant its introduction, with the attendant complications. A principal reason for this is the restriction applying in this country that " normal " engine speed shall not be exceeded on climb. It is a common experience to find that, for general-duty aircraft, an airscrew which is designed for maximum engine speed at full throttle in level flight will, with a fixed pitch airscrew, develop maximum climb at approximately normal engine speed, so that variation of pitch will not assist general performance on this class of aircraft.

The handicap of the engine limitation is partly due to engine designers having accommodated the fixed pitch airscrew and to maintenance reasons, but even so, when considering exceptional aircraft with some performance feature highly developed to the detriment of the other performance characteristics, an opportunity occurs for improving these by the use of a variable pitch airscrew. Some conditions under which variable pitch may be used to advantage will now be briefly examined.

An example of successful use of variable pitch is the landplane speed record recently set up in America. To design an airscrew to absorb the engine torque at a high value of forward speed a large pitch value is necessary, and, in consequence, difficulty is experienced at the take-off, since the airscrew blades are initially stalled. This is overcome if a variable pitch airscrew is used in such a way that the full thrust of the racing power is made available for take-off.

For unsupercharged engines, speed can only be materially improved if the specification requires maximum engine speed to occur at height; so that below that height engine speed may be regulated by change of pitch instead of by reduction in throttle opening to obtain an increase of speed at the lower altitudes. Climbing, as mentioned, must take place at " normal " engine speed, but, if the aircraft speed range be large enough to permit an increase in engine speed on climb, then the time to height would benefit.

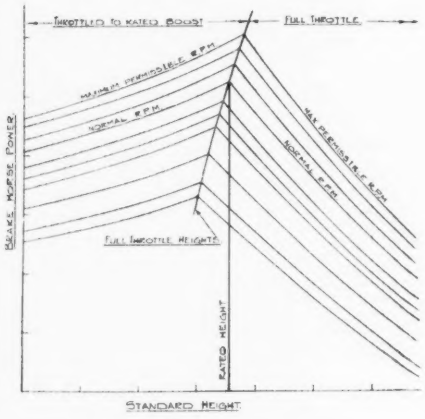


FIG. 15.

Power curves for various R.P.M. and heights.

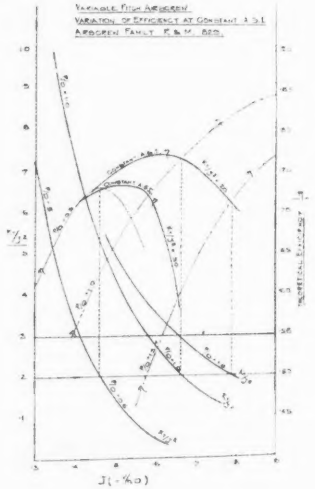


FIG. 16.

Variable pitch airscrew—family of curves.

On a supercharged engine the advantages increase as the supercharging pressure at height increases. If the engine is maintained by the throttle at constant boost pressure below the " full throttle height " it will develop an almost constant torque throughout this range. The fixed pitch airscrew is usually designed to absorb this torque at the " full throttle altitude," so that it is unable to deal with it in the higher air densities of lower altitudes, with the consequence that engine speeds and power are held down, and hence both speed and climb are reduced. With a variable pitch airscrew, however, the pitch is reduced to give maximum permissible engine speeds both for climb and top speed, and the loss in efficiency due to the higher engine speed caused by this pitch reduction is small compared with the power increase, so that the resultant performance is considerably improved.

At heights above the design altitude of the airscrew, for a given value of V/nD, the power absorbed by a fixed pitch airscrew is, of course, proportional to the relative density of the atmosphere in which it works, and for normally aspirated engines and for supercharged engines above the " full throttle height " the power falls off with increasing altitude somewhat quicker than the relative

density of the surrounding air. Hence, as an airscrew under these conditions proceeds to increasing height above the altitude for which it was designed, the torque required to turn it at a given value of V/nD gradually becomes larger than the torque available from the engine so that the engine speed falls, and this again can be mitigated by a variable decrease of pitch. The gain in performance, however, remains small.

A reduction in pitch for take-off to permit maximum power output will be more favourable to the argument for variable pitch if the blades of a corresponding fixed pitch airscrew are initially stalled, as for example on high-speed aircraft and types with highly supercharged engines operating at height; but on all aircraft the reduced pitch under static conditions gives improved airscrew efficiency as well as increased engine speed and power for all stages of the take-off.

The range of an aircraft depends on many characteristics, and, as affected by airscrew performance, is perhaps best explained by a reference to the family of airscrews shown in Fig. 16. In the notation used K_T is the thrust coefficient and J denotes V/nD. K_T/J^2 is plotted against J for airscrews of pitch diameter ratios of .5, 1.0 and 1.5, and the efficiencies are plotted on the same chart. For constant indicated air speed, K_T/J^2 is constant and the effect of variation of pitch on efficiency is obtained by comparing the curves which give the values of efficiency for the various pitch diameter ratios at constant cruising speed, and are obtained by projecting constant values of K_T/J^2 on to the respective efficiency curves as indicated by dotted lines. It is then seen that the relative merits or demerits of the scheme depend on the pitch diameter ratio of the fixed pitch airscrew with which comparison is being made. As the peak of the curve lies between the pitch diameter ratios of .5 and 1 it would appear that if the fixed pitch screw were to be given a ratio of about .75, decrease in efficiency must necessarily occur whether the pitch is then increased or decreased. For range, however, increase in pitch only is called for, since the major gain expected is due to the reduction in engine speed which reduces the specified fuel consumption. It is thus evident for a normal aircraft with relatively slow cruising speed and a fixed pitch airscrew with a pitch diameter ratio of about 1 that any improvement in specific consumption by pitch increase will be more than offset by the large reduction in efficiency caused by the increased pitch.

For a specially designed long-range aircraft, however, the situation is better coped with by variable pitch. The difficulty in take-off with large fuel load, it has been seen, can only be met for a fixed pitch airscrew by using a low pitch which absorbs full power at a speed little in excess of the initial cruising speed. This condition leads to a pitch diameter ratio of about .5, and since in the maximum pitch condition it is expected not to exceed a value of .9 there will be a definite gain in efficiency, especially at the relatively high cruising speeds entailed, which, added to the improvement in consumption, results in a range improvement to the order of 15 per cent. Additional advantages of the variable pitch airscrew are increased gliding angle through the negative thrust at low pitch, and increased speed of dive at high pitch as the engine may then be actually developing thrust without over-running.

The feasibility of changing to a variable pitch, it is seen, is not determined by any general solution, but is a question for detailed consideration in any given example. For the less standard types of aircraft variable pitch is seen to be of use, especially for take-off and range, but for general duty types no appreciable improvement is possible with engine design as so far developed.

Successful mechanical design of variable pitch airscrews depends upon solving three groups of difficulties: Firstly, provision for anchoring the centrifugal tension of each blade without undue frictional resistance to twisting of the blade; secondly, means of reacting, at the root of each blade, the resultant bending moment from air loads and centrifugal force, again avoiding excessive friction;

and thirdly, the method of varying pitch, whether manually operated or automatic with engine speed, including the interlocking of the blades to prevent independent action.

When it is recalled that the steady centrifugal pull of a blade on a moderately large variable pitch airscrew may be 50 tons it is realised that design of an adequate thrust bearing presents a difficult problem as the blade must be twisted in its socket to achieve variable pitch while under this load. Ball and roller bearings have been used successfully, but this part of the problem has been avoided in some examples by joining the pair of blades with a tension member that is sufficiently weak under torsion to allow the blades to twist through the few degrees required.

The socketing requires special attention as the blades are necessarily movable and therefore to an extent alive and will consequently tend to work in their bearings and under these conditions and the resulting high local stresses the problem of avoiding adhesion at once arises and must be solved to avoid partial seizures.

It is most desirable that variable pitch airscrews be available for a few important applications and these remarks will indicate the difficulties that have to be overcome. Fairly wide use has been made of earlier schemes in America and in this country considerable progress has been made towards successful solution and development.

Airscrew Testing

As a check of airscrew design, apart from checking compliance with engine speed requirements, an analysis of one or two flight trials does not provide sufficient evidence for determining the characteristics of an airscrew, particularly for throttled flight calculations, because of the number of variables involved, and without eliminating trials it is a matter for rough estimation only as to how much of any particular performance is due to the aerodynamic qualities of the craft or to the efficiency of the airscrew. It has long been recognised that a satisfactory instrument for measuring thrust and torque while flying would be a long step forward, but the considerable difficulties of design have not yet been successfully overcome. The full-scale wind tunnel is an advance for this type of research, but the available speed range is necessarily limited.

It is, then, due to the lack of more exact means that testing in flight relies upon calibration in the air. An aircraft is flown over a range of speed at full throttle and the power output is later computed from the enginemaker's power curves with due correction for the altitude of operation. The integrating factor relating to the torque—to continue in terms of one of the analytical methods—is then calculable, following which the thrust factor can be derived and the efficiency.

Although the method is open to errors it is found to give reliable results if used systematically, especially on supercharged engines on which the supercharging pressure is controlled. The less reliability on engines with open intakes to the induction pipe is due to the consequent uncertainty as to the actual pressure there and hence the unknown shift of the power curve.

Future Developments

No advance in design theory leading to generally improved airscrew efficiency is expected in the near future. One reason is that the general shape of an airscrew blade tends to be aerodynamically good and there is not the scope for bad design that there is in the design of aircraft. As the results of full-scale wind tunnels become more widely appreciated there will be a general cleaning up

of airscrew design theory following a better understanding of the airflow near the airscrew.

On the airscrew itself it is possible that means may be discovered of avoiding compressibility effects, or rather of making use of them, thus leading to a return of direct drive engines and thereby effecting a considerable saving in weight.

Immediate developments are more likely to lead to improved methods of manufacture, and it is certain that to a limited extent the variable pitch airscrew will be introduced to overcome some of the limitations of fixed pitch, but advance in this direction depends on mechanical rather than aerodynamical development.

In conclusion I wish to thank Mr. M. S. Hooper for his assistance in the preparation of this paper.

Discussion

Mr. E. P. Warner (Editor of *Aviation*): Before he undertook to make any comment of his own on this exceptionally valuable paper, to which he had listened with the greatest interest, he must acknowledge Mr. Fairey's kind introduction of himself in opening the meeting. He had been a member of the Society, as Mr. Fairey had said, for a number of years, but unfortunately all his visits to England hitherto had been in the summer-time, during which the Society did not meet.

In the United States they looked to the Royal Aeronautical Society with something approaching veneration, in view of what had been done under its auspices for many more years even than were covered by the historical review of the airscrew which Mr. Fairey had just made. At the time when he was studying calculus at Harvard, he remembered his professor remarking that Pappus of Alexandria had the misfortune to be a mathematician in a day when there were no mathematics. The Royal Aeronautical Society had had the courage, or the boldness, or whatever they might call it, to support aeronautical science in a day when there was no aeronautical art, and when the development of an aeronautical art seemed very far away.

Turning to the subject of the lecture, he had been struck—since Mr. Fairey had set the precedent of giving them licence to dip into history—by the remarkable analogy that the development of the airscrew presented to a variety of other engineering arts in that the progress had been through a series of cycles, or waves, from the dominance of the theoretical conception to the empirical and back again. In the analysis of aircraft structures, going back to the period to which Mr. Fairey had referred, aeroplanes were designed very largely on the basis of hope and appearance. Then there came a period, some time afterwards, when exceedingly limited calculations began to be made upon extraordinarily crude assumptions. These in due course proved to be inadequate, and in certain countries at least—rather more in other countries than in Great Britain—structural design came to depend largely upon tests of structures to destruction. That gave way, in turn, to a new dependence on analysis as other and more refined procedures of calculation came into vogue, and now they were swinging back to some extent to empiricism, as structures so complex and so redundant as not to lend themselves readily to any of the established procedures had come into being.

It was so with the airscrew. They had started with empirical design. A very satisfactory measure of efficiency was considered to be static thrust per h.p., and the spring balance was ready to give the required determination. He had hardly need to dwell upon the imperfections of that process. Then they began to get a rough system of calculation which became more and more elaborate, thanks to the work of the late Mr. Riach, and Mr. Fage, and others in Germany and elsewhere. Now, as the author had suggested, they seemed to be swinging back again to some extent to the days of empiricism, thanks to

the availability of new research methods and of airscrew designs and materials which peculiarly lent themselves to the process of choice by selection, particularly the adjustable-blade airscrew, with which it was easier and more satisfactory to place dependence upon a series of experimental curves of performance against blade angle rather than to rely upon calculation. They might again return to pure analysis. No empirical method could lead them to the sort of extremely refined determination of the dependence of single characteristics of the aeroplane's performance than upon the individual elements of the airscrew design that the author had shown in his curves of static thrust and cruising power consumption. They were, however, somewhat hampered in that progress towards complete analysis by some of the points of complication and refinement that the author had mentioned, and these difficulties would have to be overcome, as similar difficulties in structural analysis had been overcome by the introduction of more elaborate methods taking account of so-called secondary stresses. In particular the question of compressibility, for the analysis of which they were as yet almost entirely dependent upon empirical method and the laboratory, would have to be considered. The analysis on that point could, for the moment, be only a qualitative one, although progress was being made in the increased accumulation of data bearing on high speeds, speeds resembling those of the tip of a propeller blade. The difference between the changes of compressibility effect with change of rotational speed for various values of V/nD seemed not beyond their present power to explain. At the lower values of V/nD they would, in general, have the thrust centred further in along the blade; at the higher values they would secure a higher proportion of thrust from the outer portion of the blade. The thin sections gained rapidly in relative efficiency in the region where compressibility had become important, so the propeller which showed least loss of efficiency at high rotational speeds would be the propeller which did the largest proportion of its total work on the very thin portion of the blade.

There were several other points that had interested him in the paper, partly as an engineer and partly because of their bearing upon American practice, which was somewhat different from that in this country, especially in that in the States the use of the adjustable metal airscrew now had approached 100 per cent.—it was the almost universal standard.

One point that was of special interest in connection with the structure of the propeller was that they might well be able to have a freer hand at some early future date than they had now in the choice of ideal aerodynamic forms, if the hollow steel blade propeller made that degree of progress for which, with some reason, they might hope. They were no longer dependent in that case upon the blade thickness to govern the structural properties; they could, if they so desired, keep the blade of constant thickness all the way out and vary only the wall thickness, instead of having to taper off the blade thickness very drastically towards the tip in order that the centrifugal loads on the inner section might not be too high.

With regard to the variable pitch airscrew, the author was perhaps a little hard on that particular development. In America they looked upon it with more solicitude than here, in part because the geared engine had not entered into use in America to the extent which it had done in this country. In America they perhaps stood in relatively greater need of a device which would increase the thrust during take-off and preliminary climb, and they were not limited as to engine speed in climbing as they apparently were in this country.

Referring to the curves of performance of the variable pitch airscrew and the efficiency available which had been shown with special reference to the long-range aircraft, they seemed to him somewhat unfair to the variable pitch type. After all, they were not limited to the adjustment of the variable pitch airscrew so as to hold a constant r.p.m., or a constant anything else. The pilot could

be given detailed instructions for the manner in which he should vary the pitch of the airscrew, and in that case the variable-pitch efficiency curve should surely be the envelope of all the fixed-pitch curves.

There was one other important case to be considered, namely, that of the aircraft, especially the transport type with two engines, in which one engine gave out, with the result that the remaining engine was overloaded and the revolutions per minute fell off. With the variable pitch airscrew that could be avoided and the full engine power of the surviving engine, or, in the case of three engines of the two survivors, could still be obtained when most needed.

Dr. H. C. WATTS (Fellow): Whenever he had been asked to give a paper or to write in the press on the subject of airscrews he had replied he could conceive three papers. One on airscrew design, and this he could not make interesting without giving too much away; the second one on airscrew manufacture, but there he could not get permission to reveal the pet secrets of various manufacturers, and the third a careful and impartial comparison of the advantages and disadvantages of various types of airscrews—and such a paper would involve him in a number of actions for libel.

The author has done that clever thing. He had given them a very interesting paper and yet had succeeded in giving nothing away.

Nevertheless, he had written a paper which will provoke a good discussion, and that is a good point on any paper before the Society.

He rightly states that there is the strip-by-strip integration method, and there is what he called the analytical method. He agreed with his statement that the latter offers advantage of economy in computation when backed by sufficient experience, but he did not think he is right when he says it is less in use in this country than the other method. He rather thought every designer kept the empirical analytical method for his private use. He cannot talk about it or publish it because, used without his particular experience it would be useless and dangerous, and therefore, when he talks or writes in public he talks about strip-by-strip integration, although the only time he actually uses it is for official stress calculations and for window dressing.

The author makes a statement which arouses his keenest sympathies. "Introducing new designs is slow and expensive," and he would add heart-breaking. The statement applies only to metal airscrews, and the maddening part of it is that one cannot relieve one's feelings in the usual way by cursing the Air Ministry.

One knows that the procedure is necessary. Slow and expensive as it is, it is even yet inadequate. A centrifugal overload test on an electric motor tells one nothing except whether the airscrew flutters, and a 50-hour endurance test on the engine is no guarantee that it will not fail at the 51st. He had carried out a 50-hour test on a metal screw and then to make sure he had run another 50, and even then another 50, only to fail in the 145th. The only adequate test for a metal screw is something like 1,000 hours in the air, or some equivalent test on a mechanical ground tester if such an apparatus can be devised.

It speaks volumes for the reliability and safety of the wooden airscrew that it is not called upon to undergo any endurance test, and only very occasionally a spinning tower test when flutter is suspected. Its safety is taken for granted. The point is so impressive that he need not labour it.

But he noted that the author is very silent on the question of flutter, and yet this problem, until recently, has been the nightmare of the airscrew designer and influences his designs more powerfully than anything else. This, rather than aerodynamic considerations, settles his blade shape and thickness.

He did not think it is generally realised what a revolution the successful consideration of flutter has wrought in airscrew design. It is true to say that ten years ago almost every airscrew fluttered. Consequently the life of a wooden screw at any rate was anything from 20 to 100 hours, rarely more.

He thought it must be put to the credit of Mr. Lynam, late of the Royal Aircraft Establishment, that he first appreciated that most airscrews suffered from this disease. It is to his credit that, despite the jeers and protests of the industry, including occasionally himself, he insisted on spinning all new types to see that they were free from flutter. In vain it was pointed out to him that although airscrews might flutter on the tower they were frequently flutter-free in the air. He stuck to his procedure with great courage or pigheadedness, and he was right, for it is now amply proved that if a wooden airscrew does not flutter on the tower it will be safe from flutter in the air.

Flutter has now been eliminated, and not many airscrews are even spun, with the result that the wooden airscrew has gone from a life of anything from 20 to 100 hours to a life which is practically infinite.

The Society has in the past awarded its gold or silver medal for work of less value, and he would suggest to the Council that in considering their next award they might well bear in mind the administrative work of Mr. Lynam in eliminating flutter.

There is a statement made in the lecture that, to obtain the best performance, one sets the sections to give maximum efficiency. If by this statement the author means that to obtain maximum efficiency at top speed in level flight it is necessary to set the sections so that they are working at the incidence corresponding to maximum L/D he is wrong, and he was quite sure in his private designs he never does so. It is one of those statements that he (the speaker) called window dressing. It sounds right but is not.

An airscrew section of infinite aspect ratio, which is the only thing that matters in airscrew design, gives maximum L/D at about 5° or 6° angle of incidence and a lift of between 0.5 and 0.6. An airscrew designed for top speed with such a lift value would be of such a small diameter that the very large inflow would result in a very low efficiency even at top speed, and for climb and get-off it would be hopeless. Actually a lift value of about 0.3 is a more usual figure.

In the same section on the aerofoil he was pleased to note the author realises what is not generally realised, that contrary to the things they learnt in their younger days, the thicker the aerofoil section the better is it suited for all-round good performance, but he spoils his statement by going on to infer that because the thin aerofoil develops a higher ratio of lift to drag, the thin section metal blade has a great advantage over the thick wood or metal airscrew. This is another window dressing statement.

When they were dealing with airscrews having a low ratio of pitch to diameter L/D *was* important. Thin sections were dictated and thin sections could be used with impunity because the speed range was small.

Nowadays the average airscrew has a pitch equal to the diameter or more, and aircraft have a large speed range. A thick section is therefore dictated and can be used with impunity, since L/D is relatively unimportant. Between a thin section of, say, $T = .08C$ and a very thick one as much as, say, $.13C$, the difference in thrust horse-power is only one-half per cent. on an airscrew of pitch equal to diameter. L/D make little difference on high-pitched screws.

Apart from tip speed, modern conditions would dictate thick sections, but it is true that a thick section suffers more from compressibility effect than a thin one. Hence one usually keeps down to a thickness of, say, $0.1C$ on a wooden airscrew and even less on a solid metal.

On the rest of the blade, subject to reasonable speeds, one aims at thick sections except on solid metal screws where one is forced to adhere to the thin section by consideration of weight.

It must be remembered that a thin section must have a proportionately thin leading edge, and this is difficult to achieve. You may put it there but it will not stop.

A thin section with a relatively blunt leading edge may be worse than one a little thicker with a well-proportioned leading edge.

This is probably the reason why in the many full-scale comparative tests between various types of airscrews the relatively thick wooden screw has easily held its own, even where the tip speed equals that of sound.

The broad conclusion of their full-scale comparison is that there is no appreciable difference between any of the current types as regards performance. If anything it is in favour of the wooden, probably because with equal efficiency it has to raise less weight.

If, therefore, they had to decide between the various rivals they must do so on grounds other than performance.

Variable Pitch.—The main conclusion of the author appears to be generally that the variable pitch airscrew cannot justify itself except in a few special and extreme cases.

That he agreed with. It is the conclusion that anyone who thoroughly investigates the matter comes to, and if he may sum the matter up in the way he had often had to do, he would say that the successful outcome of a variable pitch proposition is at least doubtful. It is beset by so many difficulties; but, even granted the optimism to believe that these can be overcome, the uses of a variable pitch propeller are so limited that the ultimate demand would be too small to justify any large expenditure of capital.

Dr. PIERCY (Fellow): The lecturer had dealt mostly with the purely engineering side of the question. It was within the province of a leading designer to confine himself largely to an account of modern means of securing accurate design, the exactitude of which was impressive, as a result of semi-empirical methods built up on large experience. Engineers, engaged on construction of many kinds, working this way have usually managed to outstrip theory and attain high efficiency. The interesting study which the lecturer had given reminded the speaker, in reference to their happy association in bygone years at East London College, of a celebrated case where a famous one-time pupil had painted a bright and shining cherub all over the original picture. But the more particularly scientific side of the subject was important; they might look to this aspect ultimately to indicate the best arrangement for the last ounce of efficiency. Possibly, future small increase of efficiency, as to which the lecturer had not seemed very hopeful, would hang on the perfection of the science. In this connection he would like to ask whether advancement still depended on more precise knowledge of the velocity field. We now had, as a result of very recent work, a usable method of calculating the velocity field round a two-dimensional body of arbitrary shape. This might apply nearly enough to wings in the present problem. The question is whether it would not be very well worth while trying to generalise this method for solids of revolution, etc., so that the velocity fields in the neighbourhood of engine-eggs and bodies, near the airscrew, might also be calculated.

Major G. P. BULMAN (Member of Council): In the course of his very lucid and admirable paper Mr. Williams had had a few hard things to say about engines. The speaker agreed that the aircraft engine really was created only to turn an airscrew, and that it might therefore be inferred that the airscrew designer should be the arbiter of what the engine designer should permit. At the same time, the engine designer might claim that the producer of valve steels or bearing metals worked only to provide something for the engine man to use, and he might therefore accuse the supplier of the material of being illogical if such supplier said that the material he provided must not be used at a higher temperature or at a higher speed or under some higher pressure than had been determined. Every engine, like every other mechanism, was designed to work under certain conditions consistent with reliability. An engine was type tested, and the whole of its life was based on a certain speed and a certain power. In all countries other than this, he believed, the airscrew design must be such that

that normal speed was not exceeded in level flight at a rated altitude and at full throttle by more than five per cent. A distinguished American aircraft engineer confirmed that to his knowledge recently. The speaker said to him, " Well, what happens to your climb?" and the reply was, " It has to come out what it will. Why not?" In this country it had been judged by our " illogical " people that the greatest possible power must be made available for take-off and climb, and it was therefore agreed that on climb the engine should be run at normal speed, namely, the engine speed determined as the maximum cruising condition for long life. It was clear that the provision of this normal speed on climb must result in a higher engine speed in level flight; towards the end of the war period this higher or maximum permissible speed was of the order of five per cent. in excess of normal; as time went on the margin became 10 per cent., while during the last three or four years it had risen to 15 per cent., and in at least one case to 20 per cent. Yet the present author, like Oliver Twist, asked for more. He could have more if he paid for it in shorter life and in higher cost of maintenance and repair.

In referring to the increased range and better consumption secured by running the engine at wider throttle with the speed reduced by a stiff pitched airscrew, the author himself had given a direct and accurate analogy in likening the process to treading on a motor car accelerator pedal in ascending a hill. That might be all right now and again, but it was hoped that the author did not normally use his car in that way, climbing along hills on top gear with the engine knocking.

Mr. Williams suggested that the improved consumption at lower engine speed was due to reduction in mechanical friction loss, but such saving as might accrue—and it was probably very little—was more likely due to reduced pumping loss.

The author's advocacy of the variable pitch airscrew, again, was made largely at the expense of the engine on the assumption that a greater use of the maximum permissible engine r.p.m. for a greater proportion of the running time would be secured. Obviously any given aircraft would give a better performance with 600 horse-power than with, say, 550. It was for the aircraft designer to determine whether that higher output was best secured with a larger engine or by overloading the smaller deliberately, in which case he must be prepared to pay for the higher performance in terms of reduced reliability and higher maintenance cost.

Mr. Fage (Fellow): It was now ten or twelve years since he was actively engaged in airscrew research, but he still took a great interest in the subject. He wished to thank Mr. Williams for the trouble he had taken in putting on paper his experiences as an airscrew designer. It helped them to appreciate the difficulties which the designer had to face and overcome. In a way, he thought, there had not been any great change in the method of design outlined in the paper as compared with that used several years ago, he would not go back as far as the Chairman had done, but he thought he could go back ten years. He hastened to add that personally he would not expect any great change. There was still apparently an " experience " factor which had to be used. He was a little disappointed as he would have liked to have seen how far airscrews could be designed nowadays using the most modern theory. He knew that that was asking quite a lot, because, in order to check the theory, it was necessary to measure the thrust and torque of a screw in flight, and that was very difficult; but he did rather feel that there was a mass of scientific data from which a selection might have been made. He raised that point because it was of real assistance to the research worker to have some ideas as to how far he was helping the designer. Of course, there was the other point of view, that it was not always possible to apply these scientific theories to practice, but whenever it was possible, he thought such theories should be applied.

Mr. W. O. MANNING (Fellow) : With regard to the variable pitch propeller, it appeared to him to be the case that if any particular propeller was taken and the pitch varied in the way suggested, the angles of the blade would not be quite the same as if it were designed with that particular pitch originally, which would probably tend to a reduction in efficiency.

There was one other point in the paper which probably he had not quite understood, but in his remarks on the matter the author referred to the question of the compression effect depending to some extent on the speed of the propeller through the air. It would certainly be the case, if other things were constant, and the machine speed were increased, that the actual tip speed of the propeller would be increased also, and one would expect something of that sort.

Mr. W. L. COWLEY (Fellow) : One or two points seemed to him of particular importance from his point of view as one engaged at the National Physical Laboratory. The author stated that in the last Schneider Trophy season of 1930 the only gear ratio available was not low enough to accommodate the best possible airscrew, but the optimum diameter calculated for the available gear was 8.t 6in., which choice was confirmed by wind tunnel tests at the National Physical Laboratory. He thought they were all guilty at times of straining at a gnat and swallowing a camel, and this was one of the points where Mr. Williams was straining at a gnat. He did not agree with Mr. Williams there, and when considering the fact that they tested three airscrews only, he thought Mr. Williams would agree that three tests of that nature were not sufficient to prove that a diameter of 8ft. 6in. was the optimum. He would, therefore, like Mr. Williams to reconsider that last remark.

Mr. Williams had also stated that a feature of this design was the narrow rotational speed range between static conditions and top level speed. He would like to know whether that narrow speed range was an observed speed range or a calculated one. In his next paragraph the hint was given that that airscrew was not actually flown on the Schneider machine, so that he was inclined to think that that lower speed range was a calculated speed range.

That brought out one important point with regard to the calculation of static rotational speed. The airscrew was stalled under that condition, and it was the opinion at the National Physical Laboratory that no theory was adequate for calculating that condition.

In the earlier part of his paper Mr. Williams stated that the recent Schneider Trophy contests, and finally the speed record flights, provided a hitherto unfamiliar region, and that airscrews based on common theory satisfactorily reproduced design specifications in full flight without recourse to any unusual adjustments of pitch following trials. It would be very useful if he would give some figures of the adjustments that were made, because the speaker thought that a number of people did not appreciate the exact magnitude of the error which would occur. For example, with an airscrew overload of 5 per cent., the torque h.p. was down some 15 per cent. on the speed alone, irrespective of any dropping in torque coefficient, so that it followed that an airscrew overload to this extent meant that the airscrew was some 20 per cent. or more under power. A small adjustment of pitch might be given to 1 or 2°, but in effect that implied a very large error in design.

He would conclude by passing a remark on the statement at the very end of the paper that " as the results of full-scale wind tunnels become more widely appreciated there will be a general cleaning up of airscrew design theory following a better understanding of the air flow near the airscrew." The speaker could not see that full-scale wind tunnels would serve that purpose any better than the ordinary wind tunnel. For the ordinary model wind tunnel there was a mass of experimental data at their disposal, and that data had shown them that the airscrew theories were sadly lacking. A full-scale wind tunnel would afford valuable information, but one could not expect to have in the full-scale wind

tunnel such a convenient instrument as with the model wind tunnel for checking design theories and also for measuring air flow near the airscrew. For that purpose very accurate measurement was required, and in the ordinary model wind tunnel calculations were made from data relating to the supplies to the airscrew under test.

Apart from these points, he had found himself substantially in agreement with the remarks of Mr. Williams, and he wished to join with other speakers in thanking him for his paper.

Mr. E. F. RELF (Fellow) (*communicated*): Mr. Williams states that N.P.L. tests confirmed the suitability of an 8ft. 6in. screw for the 1930 Schneider Trophy machine. This is not correct; the tests showed this screw to have a high efficiency but that it would not absorb the available engine power at the stated revolutions. The optimum diameter indicated by N.P.L. tests was well over 9ft., in fact the 9ft. 6in. screw used on the S.5 was shown by the tests to be quite suitable for the 1930 machine.

Mr. F. W. JOHNSON (Associate Fellow) (*communicated*): There are a few important considerations which the lecturer has not mentioned, or which he has only referred to in passing. One is the maintenance of balance and blade shape. Another is the avoidance of blade flutter, already referred to by Dr. Watts, and another the need for the blades to be sufficiently robust to withstand impact with stones, sand or water when the aircraft is taking off or alighting. These considerations may lead to modification of the design selected to give the best performance.

The lecturer has drawn attention to the restrictions sometimes imposed on the airscrew designer, namely, insufficient ground or other clearance and engine-running requirements. In general, if the diameter is not restricted, a two-blade airscrew gives a better all-round performance than one having a greater number of blades, and the use of three or four blades should be confined to those cases where the diameter is limited through unforeseen circumstances or where excessive vibration is experienced with two blades.

In discussing the analytical method of design, the lecturer made reference to a corrosion factor for engine vibration, and he would like to know whether the author has found this factor to be large compared with other correction factors employed and also to vary with the type of engine and airscrew used.

He was in general agreement with the author's remarks on the practical difficulties of producing satisfactory variable pitch airscrews and the limited field of usefulness for such airscrews.

Mr. C. N. H. LOCK (Fellow) (*communicated*): He was interested in the lecturer's statements as to the optimum blade incidence for airscrews of various pitches and whether this optimum incidence should correspond to top speed or to climbing conditions. As regards the statement that a blade section should work at the maximum value of the lift/drag ratio, he was not clear whether this referred to the (presumably obsolete) strip theory based on aerofoil data at aspect ratio six, or to infinite aspect ratio as in the vortex theory. For infinite aspect ratio the maximum value of lift/drag occurs at a high value of the lift coefficient and calculations by the vortex theory suggest that, except possibly for airscrews of the highest pitch, maximum efficiency corresponds to a much lower value of the lift coefficient. The reason is that with a relatively low pitched screw the condition of maximum lift/drag of the principal sections corresponds to a large value of slipstream losses.

Again, in the discussion on optimum diameter, is not the most important consideration that a decrease of diameter for given power and forward speed necessarily involves an increase in the waste kinetic energy of the slipstream? In this connection the statement that the airscrew should be so designed that the translational energy in the slipstream is a maximum, surely requires revision.

He would have liked to hear more details of the methods of design actually adopted by the lecturer as it did not seem that much use had been made of

the considerable advances in airscrew theory as a result of the introduction of the vortex theory. It had always seemed to him that the airscrew was one of the few engineering problems for which a really satisfactory theory existed (apart from screws of very high pitch which would be mentioned later). He realised that the efficiency of the airscrew was so high that it was but little affected by moderate changes in design, while with freedom to twist the blade it was unnecessary to be very particular in design. He would have thought, however, that recent airscrew theory would at least be a valuable aid to experience in choosing the most efficient airscrew which will at the same time suit a given engine and aircraft.

In connection with the section on airscrews for high-speed aeroplanes, it may be of interest to notice that recent experiments at the National Physical Laboratory (unpublished) on some model airscrews of high pitch suggest very strongly that the lift coefficient of the principal sections is considerably higher than would be predicted from tests on the corresponding aerofoil sections, at angles of incidence at which the latter are definitely stalled. It may even be suggested that but for this fortunate disagreement it might have been impossible for the Schneider Trophy machines to get off the water with their existing airscrews.

The matter of the aerofoil could be expanded considerably without going beyond our present knowledge.

In general, the aerofoil section is not critical for low tip speeds, and a very fair efficiency can be obtained with considerable variation in camber ratio and aerofoil form.

The critical tip speed at which efficiency begins to fall off rapidly depends on the aerofoil shape and particularly on the camber ratio, the lower cambers making possible a very material extension in permissible tip speeds. He thought it is not so generally understood, however, that the critical tip speeds also depend on angle of incidence, the effect of increasing angle of incidence being quite analogous to the effect of increasing camber ratios. For example, they can run up to a helical tip speed of a little over 1,000 feet per second at top speed of the aircraft, while the same airscrew running under static conditions of the aircraft will begin to lose efficiency rapidly at speeds ranging from 600 to 900 feet per second, depending upon the pitch ratio.

The effect of altitude on the critical speed has not been systematically investigated, as far as he knew, but the reduction in permissible tip speed may be as great as 10 per cent. at altitude on account of the decrease in the speed of sound at the lower temperatures.

The same experiments seem to show that for airscrews of high pitch a method of strip theory calculation recently published and based on Goldstein's solution for periodic flow mentioned in the paper gives much better agreement with experiment than previous methods which assumed symmetry of flow round the axis of the airscrew, the discrepancy between the two methods becoming important for these high pitch screws.

Mr. F. W. CALDWELL (Propeller Research Engineer with the Hamilton Standard Propeller Co.) (*communicated*): The author has presented a very interesting and well-written paper descriptive of the process of aircraft design.

There are a number of points which could very well be amplified, as the conclusions to be drawn are materially affected by some of the additional characteristics of the airscrew.

The matter of pitch distribution deserves some consideration. It usually depends a great deal on the relation between body diameter and propeller diameter. For large bodies there is fairly consistent evidence that improvement in performance results from increasing the angle of incidence in the outer parts of the blades. This is probably untrue, however, near the critical tip speeds.

The matter of strength of airscrews has never been adequately discussed, as there is very little relation between the strength of the airscrew and the static or the approximate elastic stress analysis as usually carried out. If they were to follow the approximate elastic stress analysis it would be found that variations in blade thickness have very little effect on the calculated stress. We learned a long while ago, however, that a certain amount of thickness is necessary to provide torsional rigidity in order to avoid flutter.

As an example of the inadequacy of ordinary stress analysis they have a number of examples of electric motor whirling tests run for a period of ten hours at three times the normal engine power output without damage to the airscrew, followed by a failure of the same or an identical airscrew after running for 1½ hours on the engine at normal rating. They also have examples of similar whirling tests followed by 200 hours on a 400 h.p. Liberty engine without damage, and the failure of an identical propeller after 1½ hours on a 400 h.p. radial engine.

Obviously it is a little bit premature to talk about stresses, since they do not even know the loads.

Actually, most failures are caused by forced vibrations due to the engine impulses or by harmonic vibrations leading to failures at nicks or indentations.

Considerable progress is being made at the present time toward developing a suitable vibration test, and failures of the type encountered on engine test have been fairly accurately reproduced by means of accelerated vibration test.

The British specification for normal and maximum engine speed ratings is no longer logical when applied to the controllable pitch propeller, and no doubt this method of rating engines will be rapidly revised when controllable pitch propellers come into general use. It now appears that it is only a matter of a very few months until inexpensive and serviceable controllable pitch propellers will be so readily available it will be foolish not to use them.

Mr. C. H. GRIFFITHS: Does Mr. Hollis Williams find the analytical method satisfactory when designing an airscrew for a new design of aircraft for which no flight test data is available?

He agreed with Mr. Hollis Williams's general conclusions concerning variable pitch airscrews. In many of the theoretical comparisons made between fixed pitch and variable pitch airscrews it has been assumed that, with the latter, maximum permissible crankshaft speed can be used indefinitely for all conditions of flight. With crankshaft speeds restricted to " normal " r.p.m. the gain of performance possible by the use of the variable pitch airscrew is reduced and, generally, it is very doubtful if the additional weight, complication and added risk of unreliability is justified.

In addition to the weight of the mechanism adopted for pitch adjustment, metal blades have to be used in a variable pitch airscrew, as no satisfactory method of securing detachable wooden blades to metal sockets has been evolved as yet. This means that variable pitch airscrews must be considerably heavier than a fixed pitch wooden one for a given aircraft. The generally satisfactory service given by mahogany airscrews makes it difficult to state a case for fitting variable pitch airscrews except for special purposes or for an engine supercharged to high altitudes.

As regards running speeds of aero engines, the thing to remember is that " normal " r.p.m. is the maximum speed approved for continuous running. A " Notice to Aircraft Owners and Ground Engineers " states that speeds between normal and maximum permissible r.p.m. are permitted for five minutes in every hour of flight, and it is understood that in actual practice the length of time during which normal r.p.m. is exceeded is only about 1 to 2 per cent. of the total running time of an engine. In any case, if higher continuous running speeds are conceded by engine manufacturers, a gain in aircraft performance would be possible with a fixed pitch airscrew as well as with a variable pitch one.

It was interesting to note from Mr. Warner's speech that the variable pitch airscrew stands more chance of establishing itself in the U.S.A., because the American ruling regarding allowable engine speeds reacts unfavourably on performance with a fixed pitch airscrew.

He was surprised to hear Mr. Warner say that American airscrews were 100 per cent. all-metal. He had heard that, following a number of serious fatigue failures of metal airscrews, a tendency existed in America towards a return to wooden airscrews.

Reply to Discussion

Mr. Warner has summed up the situation in a masterly way and the lecturer will only deal with one or two points he has raised.

The point made by Mr. Warner about the benefits of variable pitch airscrews on multi-engined aircraft, in the event of failure of one or more engines, was of the greatest value and was a point which the lecturer had overlooked. It had a special application in the case of tandem engines, where failure of the front engine resulted in a serious loss of efficiency in the case of the rear airscrew.

In reply to Mr. Warner's suggestion of somewhat unfair treatment of the variable pitch type in the discussion of cruising economy and long range aircraft, these cruising economy curves were intended to show the available improvement in airscrew efficiency following variation of pitch at a predetermined value of indicated cruising speed. This value itself being determined by the class of aircraft, the appropriate curve of constant K_T/J^2 (or constant A.S.I.) then indicates the optimum efficiency available.

Comparison was made with the fixed pitch airscrew, and it was shown that, especially for extreme long range aircraft, improvement in range can be considerable at the indicated speed associated with aerodynamic economy. The fixed pitch airscrew is handicapped by the relatively low pitch necessary for take-off conditions with full load—for the Fairey long-range monoplane the value of the pitch/diameter ratio was about 0.5. By following one of the constant A.S.I. curves it was shown that for a wide range of increasing pitch there is considerable improvement in efficiency. This effect is, of course, added to that of the consequent reduction in engine r.p.m. at cruising speed (which results in improved fuel consumption), the two factors combining to give the improvement indicated.

Mr. Cowley has taken exception to a remark made by the lecturer that the choice of airscrew design for the 1931 Schneider race was at a later date confirmed by tests at the N.P.L.

The lecturer based his remarks on a series of three tests carried out in an N.P.L. wind tunnel on several designs of airscrew, and as his remarks were made particularly with respect to measured efficiencies, he thinks that the test did, in fact, supply confirmation.

Mr. Cowley has, however, raised some queries as to power absorption which do not enter into the present discussion, but as a result of Mr. Cowley's remarks the test evidence has been closely re-examined and a point has come to light, previously overlooked, which is that one of the model airscrews tested differed very considerably from the actual Fairey racing airscrew, which it was supposed to represent. In these circumstances the lecturer must agree with Mr. Cowley that it would be unwise to base any conclusions on the results of his wind tunnel tests.

With reference to Mr. Cowley's enquiry for information about the adjustments carried out as a result of flight trials, the lecturer would be only too pleased to supply statistics of the lack of precision obtained, were it not for the fact that actual racing conditions make this much more difficult to determine than in the case of the laboratory conditions and electric motor equipment to which Mr. Cowley is accustomed.

The actual power developed by a racing engine in the air is a very uncertain quantity due to a variety of conditions which cannot be reproduced on the test bench.

In view of this uncertainty of actual power output, the lecturer is very satisfied if a racing airscrew gives within ± 50 r.p.m. of the stipulated engine speed as it can then very easily be set, after one calibration flight, exactly to the r.p.m. required. Moreover, as the efficiency curve is very flat topped in the neighbourhood of maximum speed, small adjustments only affect the power output and not the efficiency.

During a racing season one might say that the airscrews are in almost a continual state of retwist, following changes of racing and engine policy, and due to the limitations of engine cooling available.

With reference to the discussion of the usefulness of full-scale model wind tunnels as they affect airscrew design, the lecturer based his remarks on the consideration that in the model wind tunnel it is not possible to obtain at the same time correct conditions of rate of advance and of tip speed.

He is pleased to have Mr. Cowley's assurance that this point is unimportant and can be allowed for by calculation, and that the model will be equally useful with the full-scale wind tunnel.

In addition to Mr. Cowley, Mr. Relf has also taken exception to a remark made by the lecturer about airscrew tests made at the N.P.L.

Replying to remarks made by Dr. Piercy, an exact knowledge of the velocity field around an airscrew would be of further assistance.

The work of measuring the velocity field was now going on mainly in America, and it should be possible eventually, with so much data, to design the perfect airscrew.

The lecturer's remarks about conditions of engine operation were not intended to be taken as a plea for overloading engines, but for a more judicious use of the power available.

If a little more faith were placed in pilots not to abuse engines, so much more could be done by airscrew design to bring out points of performance.

After all, the present regulations are only a partial safeguard, as they do not prevent an engine being over run if, for instance, a pilot is in such a hurry that he is prepared to lose height at full throttle. For instance a lot of speed and r.p.m. can be picked up by a loss of 500 ft./min., and starting at a reasonable height this over-running can extend well over the normal overload period.

The problem will become acute as adjustable and variable pitch airscrews become common.

The lecturer has little to add to Mr. Fage's very rational remarks.

He regrets that the fact that the scope of the paper only covered the practical application of theory, rather than theory itself, should have disappointed Mr. Fage, but he would like to remind Mr. Fage that it was so often the case in engineering that theory was mainly used to explain the result obtained by practical methods.

Mr. Manning's remark about change of efficiency due to departure from helical conditions in the case of variable pitch airscrews is quite true, and it is a matter which has to be taken into account in calculating the advantages to be obtained in any particular case for variable pitch.

With reference to the effect of rate advance of compressibility factors the latest data showed that a high forward speed airscrew would stand a lower rate of rotational speed for a given efficiency loss, than a correspondingly slower forward speed airscrew, which, as Mr. Manning suggests, is what one would expect, although there is no definite relationship.

With regard to Dr. Watts' remarks, the lecturer is pleased to know that he, too, uses analytical methods.

In reply to his long and closely-reasoned statements on the controversial subject of wood versus metal airscrews, the lecturer admits that wood is a very convenient material for airscrew construction, whereas metal presents endless difficulties and requires most careful application, nevertheless metal airscrews are a necessity especially for military purposes, tropical and seaplane use, and consequently the difficulties have to be surmounted.

Although not always the case, the lecturer does find that usually he can obtain the advantage in speed, if only two or three m.p.h., with the thin metal compared with the wooden airscrew.

Dr. Watts also deals with the question of designing so that all sections of an airscrew work at maximum value of L/D ratio. The lecturer acknowledges this correction and should have guarded himself by explaining that he was dealing with finite aspect ratio to preserve the analogy with the wing section made earlier in the paper.

In reply to Mr. Griffiths' first remark the analytical method is, for a fairly standard type of airscrew, sufficiently accurate for designing to unknown combination of aircraft and engine.

Several factors which are liable to lead to inaccuracy do not after all appear in any theory, consequently little advantage is to be gained and much energy and time spent by the use of so-called rigid methods.

The lecturer is pleased to hear from Mr. Griffiths that the step has at last been taken of defining the frequency with which five minutes overload may be used—namely, once per hour. This ruling, if freed from the restriction that the overload must only be used for maximum horizontal speed, would be sufficient to give just sufficient advantage to make the development of the V.P. airscrew worth while.

Replying to Mr. Johnson's question about the effect of engine vibration, the supposition that this might be a variable affecting design has arisen, due to it being noticed that in several cases where different types of engine are installed in the same type of aeroplane, the airscrews have widely and unexpectedly differing characteristics, and require adjustment of pitch out of proportion to the engine powers and rotational speeds.

In the absence of a better explanation this phenomenon has been attributed to the degree of smoothness of the engine, particularly as four-cylinder engines are generally found to require a higher integration factor than 12-cylinder engines. An alternative explanation may be carburation effects due to slip speed over intakes modifying the engine maker's power curves.

The differences due to one or other of these causes may easily amount to a 10 per cent. difference of factor.

Mr. Lock's first question has already been answered under replies to Dr. Watts.

With regard to the remark about translational velocity, it should be noted that in the text of the lecture the " component " of velocity was mentioned.

With regard to Mr. Lock's remarks about the uses made of the considerable advances in airscrew theory as a result of the vortex theory, the lecturer must admit that he has found no theory which could be used satisfactorily without resort to empirical factors to take into account variables not covered by theory.

The object of the lecture was mainly to deal with the normal engineering aspect and to show that although more exact methods of performance and strength calculations are available for use in dealing with any very new and complex problem, commercial requirements dictate the quickest methods and it is remarkable how seldom we feel we are treading on sufficiently dangerous and unknown ground to warrant the exact method.

With regard to excess lift, the full-scale stall of course occurs in a considerably less marked way than on a model aerofoil, but we are not prepared to admit anything phenomenal, otherwise it would show up in very much reduced engine speed.

Mr. Caldwell has made a valuable contribution to the discussion arising out of the lecture.

His remarks on the variation of tip speed effects with aerofoil incidence throw an interesting light on the subject, although they are contrary to our experience. The top speed effect does not seem to be critical, and, as Mr. Caldwell suggests, is probably very sensitive to aerofoil shape and camber ratio, as cases have occurred within the lecturer's experience of both fast and slow-moving airscrews running at radial tip speeds of well over 1,000 ft./sec. which have escaped severe efficiency loss whereas the effects have appeared in other cases under less disadvantageous conditions.

In connection with Mr. Caldwell's statement about torque variation leading to vibrations which cause failure, it is for this reason the new types of airscrew have, in this country, to carry out endurance trials on the type of engines which it is proposed to use in order to obtain approval.

The 561st Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Fifth Meeting, Second Half, 68th Session

A Joint Meeting of the Royal Aeronautical Society, the Institution of Automobile Engineers, the Institution of Mechanical Engineers, the Chemical Engineering Group, the Diesel Engine Users' Association, the Institute of Fuel, the Institute of Marine Engineers, the Institution of Petroleum Technologists, the Junior Institution of Engineers, the North-East Coast Institution of Engineers and Shipbuilders, and the Society of Engineers, was held in the Hall of the Royal Geographical Society on Tuesday, March 7th, 1933, when a paper entitled "Some Notes and Observations on Petrol and Diesel Engines" was read by Mr. H. R. Ricardo, F.R.S. In the Chair, Sir Joseph Petavel, F.R.S.

SOME NOTES AND OBSERVATIONS ON PETROL AND DIESEL ENGINES

BY

H. R. RICARDO, F.R.S.

It is usual when invited to read a paper before a scientific audience for the author to select some subject which he knows, or, at least, thinks he knows. His audience usually expects, and, perhaps, has a right to expect, to be the wiser for the information he imparts, both in the paper and in the discussion. The author would like to utter a warning at the outset that nothing of the kind is going to happen in this paper. He is going to deal with matters he does not understand, in the hope that he may be the wiser from the discussion which will follow.

He proposes to discuss two mechanical defects which are all too prevalent. For these he has no ready-made solution to offer, but it seemed to him that with representatives from so many leading Institutions present, no better opportunity could be found for debating and probing certain troubles which still vex us.

Of the two particular problems he proposes to bring forward, the first is one upon which neither the laboratory nor the test shop can throw much light, for the troubles are sporadic and occur only after long usage. In such cases, mass evidence alone can be relied upon. The second problem, that of cylinder wear, is so erratic in its incidence, that individual tests are not sufficient; here, again, mass evidence must be our chief guide, and reliable mass evidence on this subject is extraordinarily difficult to acquire, not because of any unwillingness on the part either of manufacturers or users to disclose their experience, but because so much depends on such factors as the exact position at which the wear is measured and the accuracy of records of mileage, etc., to which the measurements relate. In seeking information on the subject of cylinder wear, the author has relied on such of the published data as seemed to him convincing, in particular, that admirable paper by Mr. Ottaway last year;[1] but

[1] See Proc. I.A.E., Vol. XXVI., p. 150.

he has relied for the most part on his own personal observations. If some of the conclusions he has arrived at differ from those of others who have studied this problem closely, the difference lies probably in the manner of the sifting of the facts. No two supplies of facts, in the author's experience, are ever interchangeable; it is always necessary to fall back on selective assembly, to erect any conclusion.

During the last two years, the development of heavy-oil compression-ignition engines for commercial vehicles has spread apace, both in this country and on the Continent, and though, on the whole, they are proving a triumphant success, yet, as might be expected, certain minor, but more or less more epidemic troubles, are now appearing. Of these the most tiresome and, to the author, the most baffling, is the cracking of the white-metal linings in the connecting-rod big-end bearings. At first sight the existence of connecting-rod bearing trouble would not be surprising; it is only when we come to look into

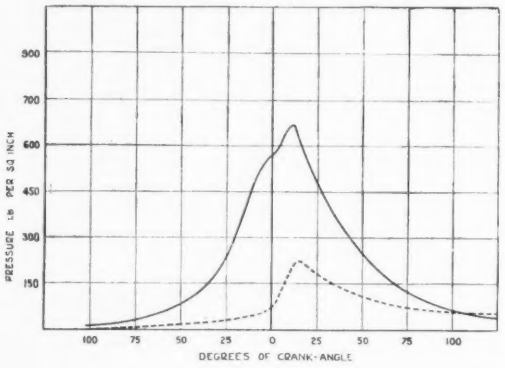


FIG. 1.

Comparative indicator diagrams taken at one-third full-load torque from "Comet" type heavy-oil engine and side-by-side valve petrol engine; 1500 r.p.m.; b.m.e.p. 38 lb. per sq. in. in each case.

the question more closely and to try and analyse or reconcile the conflicting experience that the mystery becomes so puzzling; puzzling to the author, not because the bearing linings break up, but because they fail in so capricious and yet so gregarious a manner.

Cracking of the bearing linings is more or less common to all types and sizes of Diesel engines, but the author would prefer to confine the discussion to the engines used for commercial vehicles, for, in this category, we have already a very large number of engines in operation in England and on the Continent, all of substantially similar design and dimensions, and subject to similar usage. In this field it is not so much the prevalence of cracked bearings as the almost complete immunity from this trouble experienced by certain manufacturers both here and abroad which is so difficult to explain, and, speaking from the author's experience, the more closely the facts are investigated, the more puzzling and contradictory does the problem appear.

Before dealing with the anomalies of the situation, the author would like first to compare the conditions as between a petrol and a heavy-oil engine in so far as they affect the crankpin bearing.

In commercial-vehicle service, the average load factor, or, rather, torque factor, of the engine during its running hours, is of the order of 33 per cent.;

judging from fuel consumption figures the average does not appear to vary very widely, whatever the service.

If now, in the first instance, we compare the pressure-time diagram of a heavy-oil engine with that of a petrol engine running at 33 per cent. of its maximum torque, we find that the indicator diagrams are as shown in Fig. 1, where the full line is taken from a heavy-oil engine and the dotted line from a typical petrol engine. Comparing these two diagrams, it will be seen at once that not only is the gas pressure much higher than in the oil engine, but also the period of high pressure is much more prolonged. When, further, we allow for the fact that, in both cases, a certain proportion (depending on the speed) of the gas pressure is balanced by the inertia of the piston and so does not reach the crankpin bearing, the comparison becomes even more odious.

It will be argued quite fairly that, although the average torque factor is only about 33 per cent., yet the engine of a commercial vehicle is seldom running at this actual load, for the average is made up of alternating spells of nearly

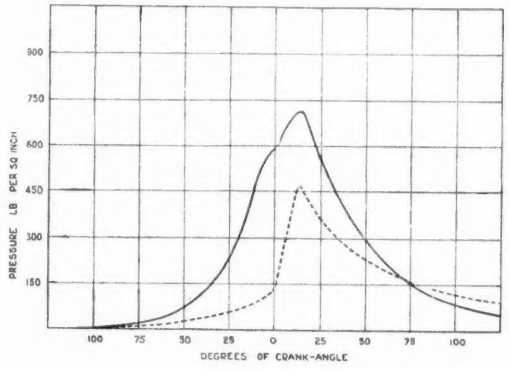


FIG. 2.

Comparative indicator diagrams taken from "Comet" type oil engine and side-by-side valve petrol engine; 1500 *r.p.m.; b.m.e.p* 108 *lb. per sq. in. in each case.*

full torque and nearly zero torque in roughly the proportion of one to two. If, again, we compare the indicator diagrams at full torque and at zero torque, we find still the same invidious comparison. Fig. 2 shows comparative indicator diagrams taken from a petrol and a heavy-oil engine when both are running at full torque at 1500 r.p.m., while Fig. 3 shows comparative diagrams taken at zero torque, *i.e.*, when idling. Here the comparison is the most odious of all. From these three comparative diagrams, and, neglecting the correction for piston inertia, it will be seen that even when idling, the maximum pressure on the connecting-rod bearing of an oil engine is considerably higher than that on a petrol engine running at its maximum torque and the pressure/time factor even more so. Small wonder then that the connecting-rod bearings should have a shorter life. If, now, we review the experience obtained so far with the many and various oil engines produced in England, Germany, France and Italy, we find, to our surprise, this situation. Roughly about 60 per cent. of the manufacturers of oil engines, both at home and abroad, appear to be suffering from big-end bearing trouble in the form of cracking of the white-metal linings, and about 40 per cent. are practically immune; it is the immunity which, perhaps, is the more difficult to explain. A further remarkable feature is the distinctness of the cleavage; thus, while of the engines turned out by 60 per cent. of the

manufacturers at least 80 per cent. will develop cracks within a certain period of time, of those turned out by the other 40 per cent., less than 10 per cent. will show cracks during the same period.

In all cases, the progress of events appears to be the same. After a certain period of service, small cracks appear in the white-metal lining of the top half of the connecting-rod bearing, right in the centre and immediately under the shank of the rod, *i.e.*, at the point of maximum rigidity; these cracks spread

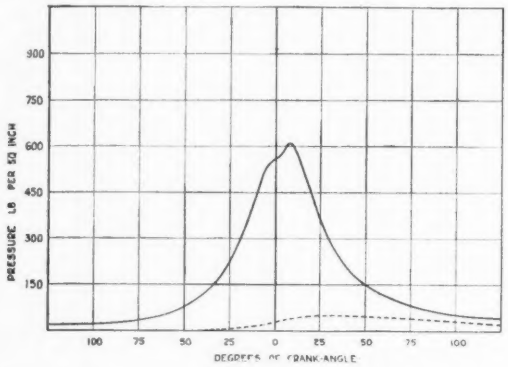


FIG. 3.

Comparative indicator diagrams taken at no load from "Comet" type heavy-oil engine and side-by-side valve petrol engine; 1500 r.p.m.; b.m.e.p. nil.

gradually and multiply until the whole surface becomes a complete mosaic. The end comes much later on when a piece of the mosaic detaches itself altogether and endeavours to climb over its neighbours. The trouble at the moment is exaggerated, as such troubles always are, in the earlier stages of development, and bearings are being examined frequently and condemned at the first sign of cracking, though, in the ordinary course of events, they could be used quite safely for at least as long again, had they been left undisturbed.

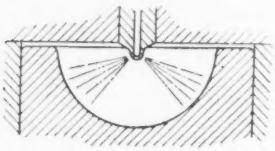


FIG. 4.

Open combustion-chamber type.

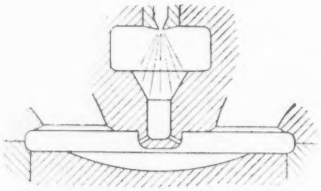


FIG. 5.

Pre-combustion-chamber type.

Apart from the question of high and prolonged pressure, various supplementary theories have been put forward in an endeavour to account both for the prevalence of the trouble and for the variety of its incidence; to some of these the author will refer later. When a trouble is epidemic in certain cases, and correspondingly rare in others, we naturally look for differences in the surrounding conditions, in the design, in the methods of manufacture, in the composition of the materials used, and so on. Let us begin with the gas

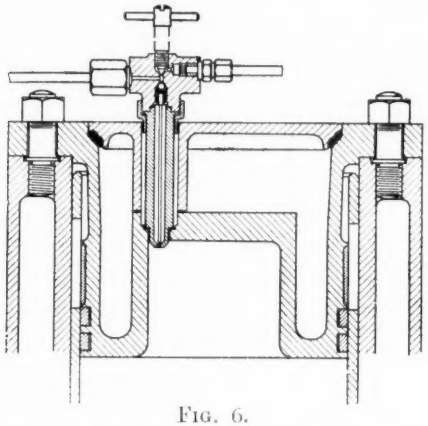


FIG. 6.
"Vortex" type applied to sleeve-valve engines.

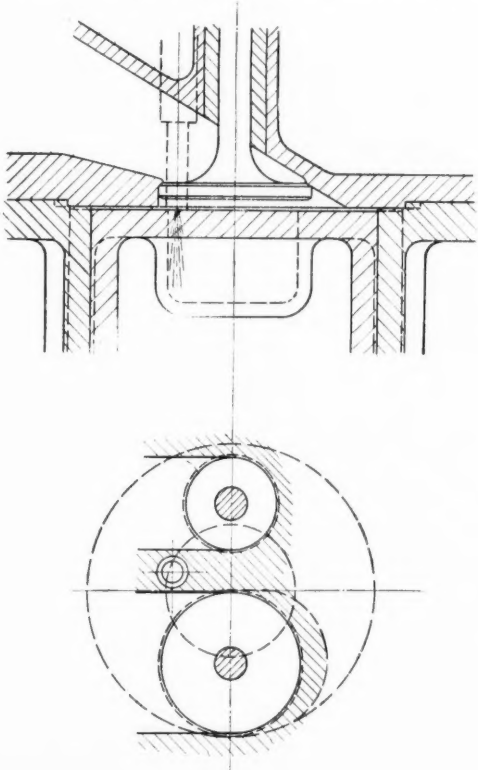


FIG. 7.
"Vortex" type applied to poppet-valve engines.

pressure conditions and consider first the general systems of working in use to-day. The heavy-oil engines in extensive service to-day in this country and on the Continent may be divided broadly into five different classes:—

(1) The open combustion-chamber type without air swirl (shown in Fig. 4).

(2) The pre-combustion-chamber type, in which a small proportion of the total combustion chamber is separated from the remainder by a partition perforated with one or more small holes (shown in Fig. 5).

(3) Those relying on rotational air swirl set up during the induction stroke in an open chamber of reduced diameter in order to intensify the swirl rate—a type which we developed some eight years ago, and which we term, for convenience, the " Vortex " type. Fig. 6 shows this as we apply it to a sleeve-valve, and Fig. 7 as we have applied it to poppet-valve engines.

(4) Rotational air swirl set up during the compression stroke, a type which we developed more particularly for road service, and which we term the " Comet " type (Fig. 8). In this, the combustion chamber, as a whole, is separated from the cylinder proper by a heat-insulated tangential passage of relatively large area. It is quite distinct from the pre-combustion-chamber type.

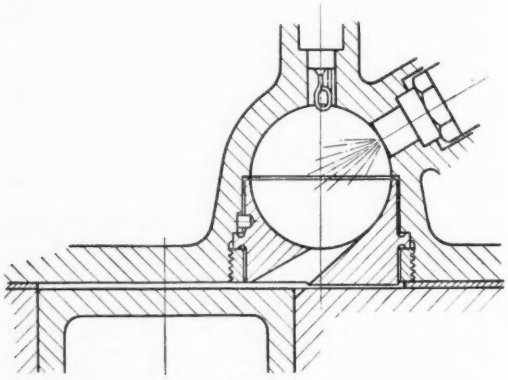


FIG. 8.
" Comet " type.

(5) The air cell or " Acro " type (Fig. 9), in which a portion of the combustion chamber is separated by a narrow neck, and serves as an air storage chamber—this type is, in effect, the converse of the pre-chamber system, shown in Fig. 5.

So far as the pressures and pressure changes are concerned, each of these types has its own distinct characteristics, thus:—

Type (I). The open chamber without air swirl. The characteristics of this type are a fairly low ratio of compression, but a very high maximum pressure, ranging from 1000 to 1200 lb. per sq. in., and a very rapid rate of pressure rise. In this type the maximum pressure is the highest of all, but, owing to the relatively low compression, about 13:1, the duration of high pressure is slightly below the average.

(II) Pre-chamber type. In this the maximum pressure is fairly low, of the order of 700 to 750 lb. per sq. in , but a very high compression must be used, and also the rate of pressure-rise is rapid. Here, then, we have lower maximum, but somewhat higher sustained pressures.

(III) " Vortex " type. In this the maximum is fairly high, of the order of 850 to 900 lb. per sq. in., the rate of pressure-rise is relatively low, *i.e.*, of the order of 40 to 50 lb. per sq. in. per degree, and the compression-pressure midway between that of the first two types. In this case, both the maximum and sustained pressures are moderate.

(IV) " Comet " type. In this type the maximum pressure is low, namely, about 700 lb. per sq. in., the compression high, and the rate of pressure-rise very low, namely, about 20 to 25 lb. per sq. in. per degree, or less than that of a good average petrol engine. Here we have low maximum, but fairly high sustained pressures.

(V) Air cell type. Here the conditions are very erratic, due to the instability of the system, and it is difficult to generalise. As a rule, however, the maximum pressure is fairly high, 800 to 900 lb. per sq. in., the compression moderately high, and the rate of pressure-rise very rapid.

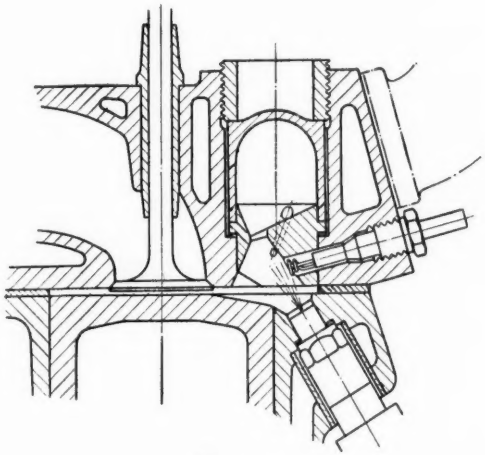


FIG. 9.
" Acro " type.

Typical full-load diagrams from all five systems are shown in Fig. 10.

When we try to relate the statistics of bearing failures to these various systems, as applied by both English and Continental manufacturers, we find:—

Type (I). At least two manufacturers of this type are virtually immune from crankpin bearing troubles; at least three are acutely subject to it.

Type (II). The pre-chamber is still fairly popular on the Continent, but is not manufactured in England for commercial vehicles. One maker of this type on the Continent appears to be immune; others by no means so.

Type (III). Two makers of this type appear to be immune; another is in epidemic trouble.

Type (IV). Two makers of this type are experiencing trouble; three appear to be immune.

Type (V). The author knows of no authentic cases of immunity in road-vehicle service where white-metal bearings are used.

From the above it is clear that we can draw no conclusions from equating big-end bearing troubles against systems of operations on the basis of their characteristic pressure changes. On the question of connecting-rod design and

bearing proportions, we find ourselves equally at sea. Within very narrow limits, the design of all is much the same. On the question of material and workmanship, here, again, no daylight appears, for the author can cite several instances where two makers, one in epidemic trouble and one immune, obtain their connecting-rods and their finished bearings from the same bulk supply. It would be reasonable to expect that speed might be a controlling factor. Practically all oil engines in commercial-vehicle service are fitted with governors to limit their maximum speed, and most drivers drive as fast as their governors will permit. The governed speed of oil engines for commercial vehicles ranges from 1400 to 2200 r.p.m., but here, again, no relation can be found; while there is perhaps a tendency for the trouble to increase with speed, it is not at all marked, and, taking particular instances, one of the worst sufferers is governed to a speed of 1600 r.p.m., one of the most immune to a speed of 2000 r.p.m. Again, on the score of lubrication, the author can find no evidence, for the conditions

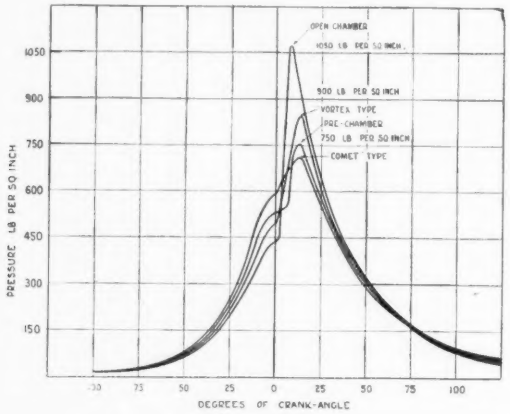


FIG. 10.

Typical indicator diagrams from :—

1. Open chamber, no air swirl.
2. Precombustion chamber.
3. " Vortex " type, air swirl produced during induction.
4. " Comet " type, air swirl produced during compression through a heat-insulated passage.

as to quantity of oil circulated, pressure, temperature, and method of introduction to the bearings are substantially the same in all cases. Engines with open combustion chambers tend to thin their lubricating oil by fuel dilution. Engines with separated chambers tend to thicken it by sludging; within moderate limits, neither habit matters in the least, as far as the author can deduce. From the fog of evidence, certain general conclusions do, however, arise; for example, it appears quite definitely to be proved—

(1) That where the design and the cost permit of the use of a hardened crankshaft, it then becomes possible to employ harder bearing linings, such as lead bronze, gunmetal, or duralumin, depending upon the difference in surface hardness between the crank and the bearing material. With these materials no such difficulties arise, but, with almost any material other than white-metal (of which the melting point is below the boiling point of the lubricant, and of which the surface is soft enough to allow any foreign body to embed itself), the danger of seizure is much more to be feared, for a seizure due to failure of the oil supply

or to the entry of foreign matter is a far more serious affair, and frequently entails the destruction of the crankshaft and much supplementary damage. Wherever possible, we always prefer to use a built-up shaft with floating bearings; for in floating bearings white-metal can be used without any risk of cracking, since the bearing is turning constantly and does not always receive the blow on the same sore place; this obviates the trouble of cracking entirely, but adds somewhat to the cost and weight of the engine.

(2) Where white-metal is used, it is best to employ very thin linings of the order of 10 to 20 thousandths of an inch carried in separate thin steel shells. This has now become the general practice.

Of the various theories advanced, the author would quote one put forward by Thornycroft and Carter, that the rapidity of the pressure-rise after combustion has started sets up what may be described as a wave effect in the connecting-rod, and under certain conditions may increase momentarily the pressure at the big-end by as much as 25 per cent. or 30 per cent. This theory is decidedly ingenious; it argues that the conditions will be most favourable when the rod is very massive and the rate of pressure-rise as low as possible.

Another theory, and one to which the author has always inclined, is that the piston should be fairly heavy and the shank of the rod as resilient as possible in order that the shock due to the rapid pressure-rise shall be absorbed by the piston mass, which has a certain amount of free movement by virtue of the shutting up of the connecting-rod. According to this theory the connecting-rod should preferably be made of india-rubber—an aluminium alloy rod, with its high elastic limit and low modulus is probably the nearest practical approach to this. We have used light alloy rods and cast-iron pistons with success, so far as immunity from cracking of the white-metal in the big-end bearing is concerned, but not yet in sufficient numbers or over a sufficient period of time to draw any definite conclusions.

Yet another theory advanced by one of the author's assistants, Mr. Pitchford, is that the damage is done at starting from cold when, owing to the low compression temperature, the delay period is unduly prolonged and even pre-ignition may occur, in either of which cases the maximum pressure will, for a few cycles, be much above the normal running figure, and that at a time when there is probably an incomplete oil film to cushion the crankpin bearing. This theory receives some colour from the evidence available; it argues in favour of the use of glow plugs or other means to assist starting, and the use of a hand pump or pressure storage chamber to force oil through the crank before starting up from cold.

None of these theories, however, will explain adequately the almost startling difference between the products of different manufacturers employing practically the same design, material and technique.

In ventilating this question the author hopes he has not given an exaggerated picture of big-end bearing troubles. They are not, even in the worst cases, of such frequent occurrence as seriously to impair the usefulness of the heavy-oil engine for vehicular work.

Again, most users of commercial vehicles are unaccustomed to the sight of cracks in white-metal linings, and are inclined to regard them as a sign of early dissolution, whereas, in aircraft or large marine engines, their presence is regarded as a more or less normal condition and the number of cracks is taken as an indication of the age of the bearing, much as the age of a tree is judged by the number of rings in its section.

Another problem which vexes us to-day is that of cylinder wear. For this, no real solution or even palliation has yet been found, despite the most devoted efforts. Wear, in some degree, there must always be, but the author is not prepared to believe that the high rate of wear we are forced to tolerate to-day cannot be made to yield to treatment. Before a remedy can be prescribed, we

have first to find the predisposing causes, and the author is not at all satisfied with any of the accepted beliefs on this subject. For many years now he has been collecting statistics and recording stray observations which may chance to have a bearing on the problem.

He has collected statistics from large slow-running stationary and marine engines, from small, fast-running engines in the same service, both oil and petrol, from motor-vehicle engines, and from the various test engines in our own laboratory, and the evidence from these may be summarised roughly as follows:—

(1) The average rate of cylinder-liner wear measured at the point reached by the top piston ring at the top of its stroke, appears to be approximately three to four thousandths of an inch per thousand hours of running in the case of petrol engines, and about 75 per cent. greater in the case of airless-injection oil engines. Lower figures are given in most of the published data on this subject,

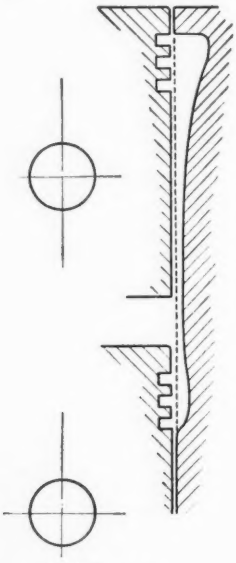


FIG. 11.

Showing typical contour of liner wear.

but the author doubts whether the wear is always measured over a zone narrow enough to record the absolute maximum, and there appears also to be rather a tendency (natural enough, but a little misleading) to lay stress on the examples of low wear to the advantage of the average.

(2) The rate of wear appears, so far as the author can ascertain, to be very nearly independent of the speed of revolution; that is to say, despite the popular belief to the contrary, he can find no evidence to show that the rate of wear per hour is greater in an engine running at 3000 r.p.m. than in one running at 80 r.p.m., provided that the pressures and the fuel are the same.

(3) The incidence and nature of the wear appear to be the same in all cases, and follow the general contour shown in Fig. 11, namely, a deep groove corresponding with the topmost position of the top piston ring tapering fairly rapidly at first, then more gradually until a minimum is reached at about mid-stroke,

after which it remains nearly constant until the end of the piston-ring travel, where it usually increases very slightly. Below the piston-ring travel, the wear is almost negligible.

(4) The author can find no evidence whatsoever that the material of the piston, *per se*, has any bearing on the rate of cylinder wear, *i.e.*, he can find no evidence that aluminium is any better or worse than cast iron in this respect, provided that, in both cases, the rings are free and in good condition.

(5) In the case of heavy-oil engines in particular, the choice of fuel has a very important bearing on the rate of wear.

(6) Apart from quite abnormal conditions, the author can find no evidence to show that the rate of wear per hour is influenced appreciably by the service on which the engine is employed.

(7) In sleeve-valve engines the rate of wear is of an entirely different order, and is little more than one-tenth that of an engine with a stationary liner.

(8) Within very wide limits the rate of wear appears to be independent of the oil consumption.

(9) Unfortunately, the author has no reliable figures relating to the rate of wear with load factor. These are very difficult to obtain, for mass evidence alone is of value, and he has not been able to acquire mass evidence from engines running at load factors other than their normal service prescribes.

The above are the very general conclusions the author has been forced to arrive at from analysis of all the reliable data he has been able to collect.

It is generally assumed that the mechanism of cylinder wear is primarily one of abrasion, pure and simple, and, for the moment, let us accept this explanation and consider how it fits with the observed facts, and let us trace out what we believe to take place during the travel of the piston up and down the cylinder.

It is agreed generally that the lubrication of a reciprocating member ranges from full fluid lubrication, while that member is moving at a fairly high velocity, to boundary lubrication when it comes to rest at the end of its travel. Under these conditions, the piston rings will ride on a fluid film of appreciable thickness during the greater part of their travel, but will approach the liner much more nearly at either end of the stroke, until at or near the actual dead-centre the fluid film will be displaced entirely, when the ring and the liner will be separated by a boundary layer of little more than molecular thickness. On the theory of abrasion (by the minute particles of grit always present in the air, the fuel, and the oil), we can understand why the wear should be at a maximum at the ends of the ring travel. Again, various observations made of the pressure changes on the underside of the rings have shown that, in the case of the top piston ring, the gas pressure behind this ring follows very closely the pressure in the combustion chamber. This was shown by Com. Turner, who took indicator diagrams from behind the piston rings of a stationary piston in open communication with the combustion chamber of a large Diesel engine, and we have made the same observation by taking indicator diagrams from behind the head sealing rings in a sleeve-valve engine. Further, we have found that, unless the gases have reasonably free access to the back of the ring, in order to force it out against the liner, the ring will not function at all, and severe blow-by will take place. That is to say, if the side clearance is made very small, or if the back of the ring groove is vented, the ring merely collapses inwards, and, in the latter case, frequently breaks up. We can postulate therefore that the pressure forcing the ring out against the cylinder wall is only a little lower than, and builds up only a little later than, the pressure in the combustion chamber. Since this pressure is at a maximum at the top of the stroke and at a minimum at the bottom, it is easy enough to understand why the wear should be most pronounced at the former place. In a sleeve-valve engine motion between the piston and the liner never ceases, with the result that a fluid film is maintained at all times between the piston rings and the liner, and not only is the wear, in consequence, reduced

to something of the order of one-tenth of the normal rate, but it is not nearly so localised. All these observations appear to fit together quite logically, and to be entirely consistent with the theory that cylinder wear is due to abrasion by minute particles of grit between the rings and the liner. The piston body itself we can absolve from all blame; it has relatively a large clearance and is free to tilt; hence it is probably separated always by a fluid film, it shows little or no wear itself, neither does the liner show any appreciable wear even where the side thrust is at a maximum. Where the author feels that this theory of abrasion wear breaks down is in the following respects:—

(1) If wear were due to abrasion alone, then the rate of wear of the rings and of the liner in terms of weight of metal lost should be much the same for both, at all events, when, as is customary, both are made from the same material. In point of fact, the loss of material from the liner is usually many times greater than that from the rings. Further, we must take into account the fact that a very large proportion, frequently the bulk of the ring wear, as measured by loss of weight, occurs on the side of the ring, where it bears against the piston land. Such ring wear as takes place is probably true abrasive wear, and we can understand it easily enough, for the ring must get very hot and bothered scrabbling against the sides of the lands of a tilting piston, and at the same time trying conscientiously to follow the contour of the liner up hill and down dale. When we take the side wear of the rings into account, as we do automatically when ring wear is measured by loss of weight, the discrepancy between the weight of material lost from the liner and from the rings becomes far greater.

(2) When materials which, by reason of their extreme surface hardness, are known to resist abrasion (such as case-hardened or nitrogen-hardened steel) are used for cylinder liners, we find to our surprise that the rate of wear is usually very considerably greater than that of cast iron.

(3) The rate of wear is out of all proportion to that observed in other parts of the engine, or to that of other mechanisms subject to similar conditions as to loading. This might be explained by the argument that the bulk of the grit is introduced with the air; hence the lungs will suffer most; but against this argument we have the observed and fully established fact that marine engines operating presumably in a nearly dust-free atmosphere suffer quite as severely as road-vehicle engines.

(4) In the case of heavy-oil engines, the rate of liner wear is closely dependent on the fuel and increases rapidly with fuels of high ignition temperature, as Boerlage has shown.

The above considerations, to the author's mind, are sufficient to throw a grave doubt on the theory that liner wear is to be accounted for by abrasion alone, or even by abrasion as the major factor. About a year ago, and partly also as a result of some stray observations, he formed the belief—he cannot yet call it more than that—that the greater part of the loss of metal from the cylinder liner is to be accounted for by direct corrosion by products of partial combustion. We know well, and anyone who has experimented for long with heavy-oil engines has had it brought home to him very forcibly, that when the flame is chilled suddenly by contact with any relatively cold surface, the process of combustion is pulled up short and partial products, some of them strong oxidising agents, are let loose. These, owing to the sudden drop in temperature, are compelled to abandon their attempts to satisfy their appetite in the normal way, and cling to the walls, hungry for what they can devour.

The author's conception, then, of what occurs is somewhat as follows:—As the piston approaches top dead-centre, the protecting oil film between the rings and the liner begins to break down, and at the same time the pressure behind the ring begins to rise. At top dead-centre the ring is stationary for an instant and the pressure behind it is rising rapidly; what little oil remains is squeezed out until no more than a layer of molecular thickness is left, and the surface of the

liner at that point has been squeegeed until it is practically dry. As the piston begins to descend, the pressure behind the ring is still building up, and some appreciable distance is travelled before the velocity is such that the ring will again be lifted and ride on a fluid film. Now as the piston descends further there is left exposed to the flame a band of the liner of indeterminate depth from which the oil film has been wiped almost clean, and which is therefore largely unprotected from direct attack by the products of partial combustion. On this exposed sore they settle like flies, and satiate their appetites with the bare metal. On the next cycle the surface is again scraped clean by the rings and prepared for a fresh attack.

In support of this belief, the author would like to cite the following stray observations which have been noted from time to time:—

(1) Some years ago the cylinder of a large experimental petrol engine blew clean off during a test. Within less than 30 seconds after the engine had been running normally a band of rust had appeared at a level corresponding with the position of the top ring at the top of its travel. The remainder of the bore above and below was well lubricated. Opportunities for such an observation are rare, for, in the ordinary course of events, an engine cannot be stopped in full swing or before it has turned a few revolutions without combustion taking place, and this has removed all evidence. An accident such as that mentioned afforded just such an opportunity.

(2) It is general experience that the cylinder liners of the high-pressure air-compressors used for blast-air injection in Diesel engines show only a very small fraction of the wear found in the combustion cylinders, despite the fact that the pressure conditions are much higher. This, the author thinks, is very significant.

(3) In petrol engines combustion as a whole is usually fairly complete, and partial products are formed only when the flame is chilled by impingement against the walls. In Diesel engines combustion is often by no means so complete, and partial products are more prevalent. Boerlage and others have shown that cylinder wear is largely dependent on the nature of the fuel, and Boerlage at any rate has gone further, and has shown that wear increases as the self-ignition point of the fuel is raised; that is to say, as the combustion is delayed or rendered incomplete.

We have recently carried out a series of tests which are practically the converse of Boerlage's. In these, instead of changing the fuel, we used the same fuel throughout, but changed only the cylinder head. In one series of tests we fitted a cylinder head with a combustion chamber designed to give as complete combustion as possible, and, by directing the flame, we endeavoured to prevent it from impinging against any cold surface, in order to reduce to the minimum the formation of products of partial combustion. In the other series we employed a form of combustion chamber which, though in general use, produces a large proportion of these products, and these can be detected at once by the pungent smell of the exhaust. The tests were carried out in a series of ten-hour spells at different loads, after each of which the whole of the lubricating oil was collected and tested for the presence of iron. The results of a large number of tests on the two different types of combustion chamber are shown in Fig. 12, from which it will be seen that with the chamber designed to suppress as far as possible the formation of products of partial combustion, the amount of iron oxide found in the lubricating oil was a fraction only of that found in the other case; moreover, in the former case, the amount of iron oxide was practically constant and independent of the load, while in the latter it increased rapidly as the load was increased and the flame reached further towards the cold walls. Some of the iron found in the lubricating oil may have been carried in with the air, and some may be due to wear in other parts of the engines, but such outside influences must have been present in both cases, and should not affect the comparative value of the observations.

(4) The fact that surface hardness helps very little, if at all, is inconsistent with the theory of abrasive wear; it is not, the author thinks, inconsistent with that of corrosion.

The author does not feel that there is yet enough evidence to justify him in putting forward the theory of corrosion as the chief factor in cylinder wear, as anything more than a debating point, but he submits that it can be made to account for certain anomalies. It will account, for instance, for the huge discrepancy between the rate of wear of the rings and the liner. If the progress of events is such as he has suggested, and if corrosion were the *sole* cause of wear (which he does not for a moment suggest), then we should expect to find no wear at all on the piston-ring face—we do, in fact, find relatively very little. It will account, as suggested already, for the large difference in the rate of wear between internal combustion engines and, say, high-pressure air-compressors. It will account for the relative absence of wear in sleeve-valve engines, though this can be explained also, but with less conviction, on the theory of abrasion alone. Other observations are needed; for example, on the corrosion theory, and

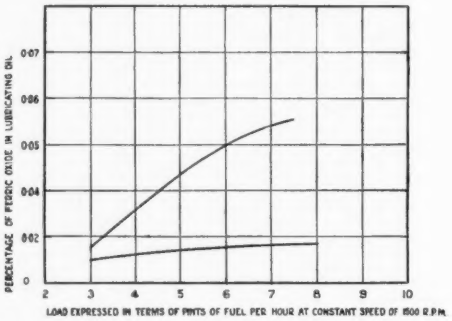


FIG. 12.

Relative proportions of iron found in lubricating oil during comparative 10-hour tests at various loads with two different combustion chambers. All other conditions the same.

in the case of petrol engines, at any rate, we should expect wear to be least in air-cooled cylinders where the surface chilling will be at a minimum, and we should expect it to grow worse the cooler the cylinder walls are maintained, and much worse if they could be kept so cool as to enable the partial products to find water to whet their appetite.

The author thinks that there is some indication that wear is less when the cylinder walls are kept hot, as in air-cooled engines, but he has not yet been able to get sufficient data to be sure of this. If it should be proved, as he is inclined to think, that corrosion is the primary or even an important factor, then we must revise altogether our ideas as to how to deal with the trouble—we shall need nasty-tasting, rather than hard liners, and the problem will become one for the chemist rather than the engineer. Again, we shall have to concentrate our attention on means for preserving a protecting oil film—so far a moving liner or sleeve-valve seems the only practical solution of this, but it should not be beyond the wit of man to devise other means. Certain cast-iron compositions are found to resist wear better than others; for example, high chromium and high phosphorus contents appear both to help—are they less susceptible to corrosion? The author is suggesting, in short, that we may have to take the baby from the surgeon's care and hand him over to the pharmacist.

Discussion

Mr. H. T. Tizard, F.R.S., F.R.Ae.S.: The author says that the lubrication of a piston " ranges from full fluid lubrication . . . to boundary lubrication." What does he or anyone mean by boundary lubrication? He supposed that a safe definition, in their present state of knowledge, would be to the effect that boundary lubrication occurs when surfaces are so close that the conditions of fluid lubrication cease to hold. But the author assumes that at the end of each stroke " the ring and liner will be separated by a boundary layer of little more than molecular thickness." He did not think there was any evidence for this statement. If they assumed full fluid lubrication over the range of piston travel where there is very little wear, it follows that the time available for the oil film to be squeezed out at the end of each stroke is of the order of one-thousandth of a second in a high-speed engine, and is certainly not so great as one-hundredth of a second. Surely it is impossible for a film of oil to be squeezed completely out in this time, however great the pressure. He concluded that the thickness of the film between the ring and the cylinder is much greater than molecular thickness even when the piston is momentarily stationary.

The author refers to " high rate of wear." Is it so very high? It is stated to be between 0.003 and 0.004 in. at the top of the piston stroke per 1000 hours' running, and to be practically independent of the rate of revolution of the engine. This amount of wear is roughly 0.001 cm. An engine running at 1800 r.p.m. will do over 100 million revolutions in 1000 hours. The surface of the cylinder is rubbed over twice per revolution, so that it is rubbed over 2×10^8 times in 1000 hours. The diameter of one atom of metal is of the order of 10^{-8} cm. Now the smallest layer that can be scraped off each stroke is a layer of one atom in thickness. If such a layer *were* actually scraped off each stroke, the wear in 1000 hours would be $2 \times 10^8 \times 10^{-8} = 2$ cm., instead of the observed wear of 0.001 cm. The discrepancy is so great that he thought that the author's picture of the events must be wrong in detail. He may reply that he was treating the surface as if it were perfectly smooth, which it is not, and though that objection would be of great force if they were thinking of the wear as due purely to abrasion of metal, he thought it loses its force if they were merely considering the removal of transitory layers of oxide. On the other hand, the author has brought forward very powerful arguments in favour of his view that wear is largely caused by corrosion. He concluded, therefore, that if it is caused by corrosion it occurs only when engines are being started up, and that when once the engine is hot no further wear by corrosion occurs.

He thought the conditions must have been peculiar that when the head of a cylinder blew off a visibly rusty ring was formed at the top of the stroke, because if that amount of rust were formed during each stroke the cylinder would wear away in an hour or two. Can the author say if any observations have been made on gas engines, which can operate on very weak mixtures and, therefore, under conditions when combustion is complete, and there is little tendency for the formation of acidic products of partial combustion?

One further point:—corrosion can hardly be a factor in causing wear at the bottom of the stroke, otherwise why should it not cause wear all the way down the stroke? It seems possible that the wear at the bottom of the stroke is an " abrasive " wear, due to the fact that although the surfaces of the ring and liner are separated by a layer of oil of more than one molecule in thickness, they are nevertheless sufficiently close to come within the range of molecular attraction. Hence, some atoms of metal are torn away at each stroke. If this view is correct, it is only the additional wear at the top of the stroke that is caused by corrosion, and then only during starting and warming up.

Dr. A. E. Dunston: He could not help thinking that the propagation of a wave motion from the heavy combustion shock has a very definite bearing on

the subject of the cracking of connecting-rod bearing liners. It is very gratifying to hear the definite expression of opinion by the author as to the outstanding success of the compression-ignition engine. Its " teething " troubles, which every new proposition has to encounter, will surely be solved. In connection with the question of liner wear, he hardly thought that the nature of the fuel has been stressed so much as it should have been. Theories have been put forward concerning erosion, abrasion, and corrosion, but what part, if any, in these activities is played by the chemical nature of the fuel? He was not prepared to accept the theory of definite chemical action at the top and bottom of the stroke. He could not visualise the scraping away of the lubricating oil so as to leave a clean, chemically attackable surface. When the author speaks of a uni-molecular layer he imagined that a uni-molecular layer of a chemically inert lubricating oil is just as good in stopping corrosion as a layer ten thousand molecules thick. He could not postulate a chemically clean metal surface which will be attacked by some entirely unknown products which are merely described as having an acrid smell. What are these products? How do they act and what is the evidence in the Diesel cycle that partially burned products are being produced which are highly corrosive to steel? In his own laboratory a considerable amount of work has been done in connection with this particular problem, and it is significant to mention that engines running on petrol as compared with road performance, and at a higher load factor, show only about one-tenth to one-quarter of the wear that is experienced under road conditions. To what is the difference between laboratory and road conditions due? It is simply the difference between practically no abrasive material in the laboratory tests, where the lubricant is frequently changed, and the air clean, and the continual introduction and accumulation of abrasive material in the vehicle when running on the road. If chemical corrosion were really a factor in cylinder-liner wear, the sulphur content might be thought to be to blame, and it is, indeed, often blamed for all the faults that are encountered. The point is that if corrosion is due to the sulphur content, why is it that a petrol engine on the road will show more wear than a Diesel engine in marine service, although the sulphur content in the two cases may be as 1 : 100? Is it not reasonable to assume that cylinder-liner wear and ring wear are, to a certain extent, dependent on the particular metallic characteristics of the metals of which these two parts are composed? His own laboratory was inclined to think that abrasion rather than corrosion is the source of the trouble. The presence of rust on the active part of a cylinder could be chemically determined, and he would like to ask whether the alleged rust noted by the author on the cylinder of which the head was blown off was so examined? Was it really rust, due, for example, to the impact of mere moisture on a comparatively clean surface? If the iron in the lubricating oils was determined under really comparable conditions, is not the iron the synthesis of both erosion and corrosion, and who can actually apportion the blame? The author's final words appeared to him, as a chemist, to be very sound. The chemist must come into the picture, but is the picture adequately drawn?

Mr. Tom Thornycroft: With regard to the bearing trouble, he preferred to believe that if bearings are well designed and good workmanship is put into them, the results will be satisfactory. Nevertheless, they were very dependent on the personal element—the workmen—while dirt may play its part, and that is largely the reason why some bearings run well and some do not. Although the author stated that some of the bearings came from the same manufacturer, it is possible that they were not put into engines with sufficient care.

The question of cylinder wear is a more complicated matter, and he felt sure that load factor has a very large influence. He had data from some hundreds of vehicles which prove that with a low load factor and vehicles only running short distances, the cylinder wear is as much as five times as high per mile as in the case of vehicles running long journeys at a reasonable temperature and load

factor. Some seven or eight years ago experiments were carried out in America in the laboratory in which in something like 24 hours the cylinder was completely worn out solely by stopping and starting and running a freezing mixture through the jackets. He had run engines for about 2,300 hours in 300-hour runs with very little cylinder wear, but they have been running continuously at nearly full load at a reasonable temperature, which all goes to prove that something other than just erosion is wearing the cylinder.

With regard to dirt, they had two vehicles running in the Sudan for two years, one without any air cleaner, and the other fitted with the best air cleaner we could get, and they found practically no difference in wear between them.

With regard to rust, he had found a definite rust film for two or three inches down two cylinders of a London bus engine, which had been stopped for about 20 minutes after being on service all day.

Years ago, too, when water was added to the inlet of a paraffin engine to prevent pinking, cylinder wear was increased to an enormous extent, probably due to corrosion. They would like to know what corrosion is, as no doubt it has many forms, and they must find out the correct antidote for cylinder wear. Certainly Mr. Duff, who is looking after the experimental work of the Research Committee of the Institution of Automobile Engineers, is able to furnish evidence that some of the author's theories are accurate.

Mr. W. N. DUFF: The Research Department of the Institution of Automobile Engineers has been making investigations into the question of cylinder wear. The results are confidential to the organisation, but in view of the suggestion made by the author with regard to corrosion he had been given permission to disclose a portion of their investigations.

They had been running petrol engines under varying conditions in their testing laboratory at Chiswick, and they found that the rate of wear under steady running conditions was extraordinarily low—less than half that which they had been led to expect from the information they had received from manufacturers as to the average rates of wear. This led them to the conclusion that they were not properly reproducing service conditions. They had been told that the wear occurred largely when starting up, that the dilution of the lubricating oil by petrol was the cause of cylinder wear, and that scanty lubrication also caused wear. As a consequence, they made some tests with the lubricating oil diluted with paraffin, even up to a proportion of 95 per cent. paraffin and 5 per cent. lubricating oil, and they got no increase of wear. They tried cutting the oil consumption down to practically nothing, and they still got no increase in wear, and they began to wonder whether this engine would ever show any signs of appreciable wear. Then they made a series of starting and stopping tests. They ran the engine for a quarter of an hour on three-quarters load and then gave a quarter of an hour rest, during which the jackets were cooled by the circulating water. This cycle was repeated many times and wear measured. These tests gave a little more wear than they got previously under steady running conditions, but the wear was still ridiculously low. Bearing in mind that the oil may not reach the cylinder walls for perhaps five or ten minutes when starting from cold under ordinary working conditions, they repeated the cycle, but supplied no oil at all to the walls for the first five minutes, but the wear was just the same. They then supplied no oil for ten minutes, but still there was no increase in wear. They then repeated the test, strangling the carburettor and so washing the oil off the cylinder walls, but still there was no more wear. They then made the running period half an hour and did not turn on any oil for the first 25 minutes, and even then they could not obtain wear.

They then ran the engine under steady running conditions with water going through the jackets all the time, keeping the jackets down to a very low temperature and they immediately got a very high rate of wear; so they began to wonder why the starting and stopping did not give them a high rate of wear.

They got out a temperature/time curve for the temperature of the cylinder walls and had a thermo-couple as near to the cylinder bore as possible. Their cycle was as shown in Fig. 13. The temperature rose to a steady value of 120° after about 2½ minutes. At "A" they stopped the engine and cooled it down; the next cycle started at "B." The dotted curve shows the cycle with thirty minutes' run, when the oil was not turned on for twenty-five minutes.

These curves show that although such things as lubrication, strangling, and other conditions altered, one thing did not alter, and that was the small area shown shaded, corresponding to the time when the engine was running below the normal operating temperature. The only other thing that did not alter was the wear, and it occurred to them that if they increased the shaded area they might increase the wear. They therefore ran another series of tests, idling the engine for the first five minutes and then running on three-quarter load for ten, followed by a quarter of an hour's rest; and got a curve like that shown chain-dotted and, at the same time, they got eight times the amount of wear compared with the previous test. In other words, the wear during the cycle when the engine was idling for five minutes on starting, followed by ten minutes' three-quarter load, was eight times what it was when the engine was running at three-quarters load for half an hour, with no lubricating oil supplied to the walls for the first twenty-five minutes of each run! This test, together

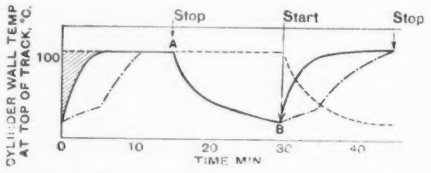


FIG. 13.
Temperature/time curve.

with the pitted appearance of the piston rings and the observed quantity of moisture in the oil, led them to the hypothesis that the rate of wear depends on the temperature of the cylinder and that corrosion forms the major part of the picture in this question of wear. It is interesting to know, also, that whether it is a molecule or many molecules thick, the presence of pure mineral oil is not necessarily a sure guarantee against corrosion.

During the last two months they have been running engines under varying conditions with varying fuels and oils. They have used four different engines at varying temperatures, but he was not at liberty to say more except that they have been able to draw a curve of wear as a function of cylinder-wall temperature, similar to Fig. 14.

This shows a practically horizontal line from about 300°C. down to 100°C. Between these temperatures the rate of wear was practically constant, and also practically independent of the quantity of oil supplied. Below 100°C. the curve begins to rise and the slope increases very rapidly as the temperature falls. At 50°C. the rate of wear is just eight times that at about 100°C., and it is interesting to note that the beginning of the bend of this curve corresponds to 90°C., which exactly corresponds with the dewpoints of the products of combustion in the cylinder. About one gallon of water is produced for every gallon of petrol burned, and that means a dewpoint of about 90° at one end of the stroke and 50° at the other, and it is at 90° that this curve begins to turn. That curve is with very low lubricating oil consumption, but they have drawn another curve (shown dotted) for more generous lubrication. In other words, this

question of corrosion is aggravated by shortage of oil and can largely be mitigated by increasing the supply of oil.

He thought that these tests are an answer to the author's question as to whether wear increases as the cylinder walls are kept colder. He did not say that corrosion accounts for everything, but he did think it is a most important factor and they have definite evidence that whether wear is due to products of combustion or not, it does definitely require condensation to make it become something appreciable.

During their investigations they received many and varied suggestions. Some of them were quite dogmatic, that certain factors were *the* cause of cylinder wear. He thought they had disposed of some of these suggestions, and it is interesting to know that suggestions as regards corrosion were received from two people, one being the author of the paper, and the other the Chairman of our Executive Committee, Mr. Tom Thornycroft.

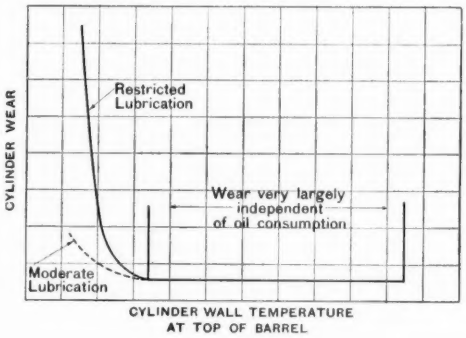

CYLINDER WEAR
Restricted Lubrication
Wear very largely independent of oil consumption
Moderate Lubrication
CYLINDER WALL TEMPERATURE AT TOP OF BARREL

FIG. 14.

Wear as a function of cylinder-wall temperature.

Mr. A. E. L. CHORLTON: Before the war they had engines up to 500 h.p. per cylinder; these were water-cooled engines, and the same difficulties of cylinder wear took place as take place now. That was a type of engine which is similar in weight to the marine engine of to-day. No cure, however, was discovered for a long time, and any question of natural rise in temperature of the circulating water could not have been countenanced for a moment in those days, because it was the belief that the temperature must not be raised to boiling point. The conclusion they arrived at in the end was that the piston rings themselves had a great deal to do with cylinder wear, and that the increase at the end of the stroke was partly due to the action of the ring in moving by the reversing of the motion. Thus the wear was more due to the fact that the ring itself did not really act freely. They finally decided that the next step to take was to lubricate the cylinder walls all over as much as possible in such a manner that they would not get an excess behind any ring, and yet make certain they always got oil on the cylinder walls about the end of the stroke. In this particular engine fourteen points or feeds were put through into the cylinder lining face for lubrication and from their use complete success was attained. They got a fine film of oil over every part of the cylinder wall, and the rings were kept lubricated exactly alike. There was never so much behind them to build up an excess and carbonise, but there was just sufficient to make them work free and keep tight. This appeared to effect a cure, and they never had any further bother with cylinder wear.

With regard to big ends, they ought to be careful not to take anything put forward to-night as being the final word. He agreed with Mr. Thornycroft that accuracy in design and manufacture should largely prevent any trouble with bearings. In the development of the R.101 engines, combustion problems were solved by 1924, but it took them until 1929 to get the crankpins right, and that largely turned on a question of the stiffness of the rods and the accuracy of the white-metal bearing linings. Whether the rod should be cushioned, he was unable to agree; his view was that they should have strong stiff steel bushes (lined) with an oil film behind, against the surface in the rod, and under these conditions, with good manufacture, there should not be any trouble with bearings.

Mr. G. D. BOERLAGE: They had found in their laboratory that wear is caused mainly by defective combustion, which they have called " half combustion," which results in sticky or acid products. Their conclusion is even that

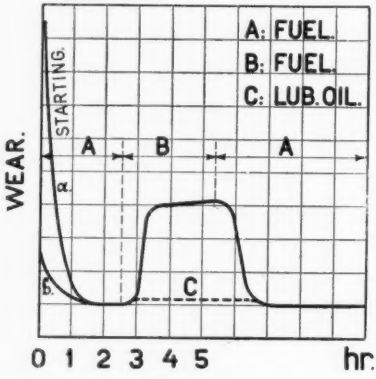


FIG. 15.

Wear plotted against time.

often wear can be smelt. It should be understood that one of the causes of " half combustion " may be too high a self-ignition temperature of the fuel or, as they measure it to-day, too low a cetene value. (The cetene value of Diesel oil is comparable with, although in many respects the opposite of, the octane value of petrol.) Some engines are very sensitive to this characteristic of the fuel, whereas others are almost insensitive. The non-sensitive engines, the " omnivorous " engines—and these are the bigger engines and the better designed small engines—have with fuels of relatively low cetene value quite a good combustion and no extra wear.

Thus there is danger in generalising and saying that wear increases with the self-ignition. This holds only for poor designs.

He would like to give a few results of the wear tests in their laboratory, where they had developed a method of controlling wear in a continuous way over a short time.

Fig. 15 shows wear against time.

a shows the abnormal wear after careless starting.

b the improvement with careful starting. The wear is seen to be practically constant after some two hours.

Changing over from fuel A to fuel B, which was a rather heavy and dirty one, very serious increase in wear is measured, but the wear again becomes practically constant after a few hours. Changing back from fuel B to fuel A, the old level is regained. The difference between A and B may be attributed to

" half combustion." It is also interesting to see the influence C of a change in lubricating oil; it has practically no effect. He would not say that any lubricant can be used, but normal lubricating oils will show only very small differences in wear.

Fig. 16 shows the influence of " running in " a new engine; it demonstrates that it takes a long time before a constant line is given. Undoubtedly in this case the difference must be attributed to abrasion.

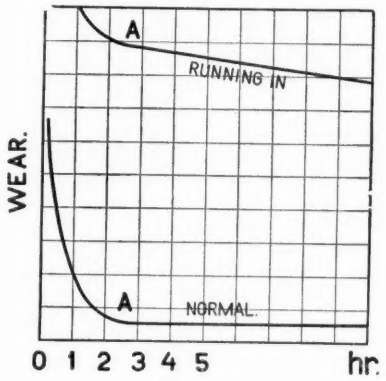


FIG. 16.
Influence of " running-in."

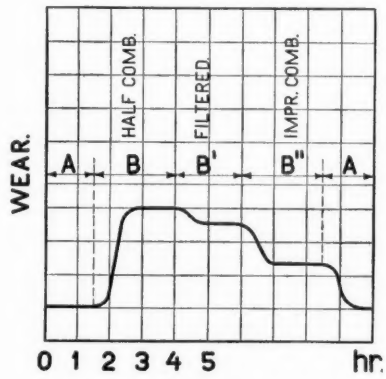


FIG. 17.
Influence of filtering fuel.

Fig. 17 shows the influence of filtering the fuel B; it is not of much effect (B′). On the other hand, B″ shows the result of improved combustion, and it is clear that with the same fuel the wear is now reduced to a great extent, which illustrates the danger of " half combustion."

Mr. D. R. PYE, F.R.Ae.S.: His contribution would be rather in the nature of sidelights, based on a comparatively small number of relevant observations. On the question of big-end bearings, it is true that cracking of the white-metal is not uncommon in aero-engines, although he deprecated somewhat the author's suggestion that it is normal. The white-metal in many designs of aero-engines

is run direct into a very light steel shell, and he thought that the cracking is to be associated with the difference between the elastic properties of the steel and the white-metal under the influence of the varying forces on the big end. As he saw it, the problem was this: that the steel shell deforms or flexes, to a degree which the steel is able to put up with without distress; but at the working temperature the white-metal has virtually no elastic properties, and hence fatigue-cracks very rapidly develop. How far that flexing takes place will depend very much on the detail design of the bearing. He could not agree with Mr. Thornycroft and Mr. Chorlton that with good enough workmanship there will be no trouble from cracking, because there are many cases of aero-engines in which the technique of manufacture has been carried to the highest possible pitch of perfection, and yet this cracking occurs. The author has shown that it is almost impossible to co-relate this cracking with the different type of combustion, but he did not say how far he had been able to examine in detail the different designs of big-end bearings. Would it not be possible to get some kind of order out of chaos by examining the designs of the connecting-rod big ends to see how far this flexing may be different in different designs? He had in mind the Beardmore engines fitted in the airship R.101. The very persistent trouble from the cracking of the white-metal in the big ends of these engines was cured almost entirely by a process of stiffening the steel shells which carried the white-metal.

Turning to cylinder wear, he could give only negative evidence; Mr. Hall, the chief engineer to Imperial Airways, had assured him that on the engines for which he (Mr. Hall) was responsible he had been entirely unable to detect the smallest difference between the cylinder wear in those machines which operate over desert routes and through sand storms and those which are on over-sea routes, and operate under conditions where at least they are free from anything in the way of abrasive influences. He thought the very fact that cylinder wear is so small as to be virtually unimportant in the life of a normal aero engine, is in itself a matter of some interest in relation to this discussion, because there are two conditions in which the life of an aero-engine differs from that of a road transport engine. One condition is that on an average the cylinder temperatures are much higher, and the other is that aero-engines operate with a much higher load factor. In other words, they are not continually stopped and started, and there is not the frequent operation of the strangler, with its effect of washing the oil from the cylinder walls. On both counts, therefore, aero-engine cylinders are less subject to the corrosive conditions which Mr. Duff has described. He must say that, after hearing Mr. Duff's contribution to the discussion, he would be inclined to go further than the tentative suggestion which the author has put forward that corrosion is an important factor in cylinder wear. When, about a year ago, this question of cylinder wear was discussed by the Research Committee of the Institution of Automobile Engineers, there was some debate as to the possibility of lifting this puzzling problem out of the sphere of mass evidence, and of isolating the true causes of cylinder wear by doing controlled laboratory experiment. It appears to him that Mr. Duff and his co-workers have to a very large extent provided the controlled laboratory experiments which were needed, and he thought that the Research Committee of the Institution is to be congratulated on a most successful piece of work.

Capt. G. S. WILKINSON: Mr. Pye has put forward some reasons for suggesting that the flexibility of big ends accounts for the cracking of white-metal. Within limits he agreed with this, but he had found that while stiffening the big end a certain amount has reduced the amount of cracking, stiffening beyond a certain point does not produce any further reduction of cracking.

Several years ago he had an interesting experience with an engine in which oil was fed to the crankshaft from one end only and the only oil flowing through the shaft was that which leaked through the big-end bearings. The rod at the end of the crankshaft adjacent to the oil feed was quite satisfactory, but the rods

became progressively worse towards the other end. Drilling a small hole of about $\frac{3}{32}$ in. diameter through the shaft at the far end from the oil feed immediately reduced the amount of cracking and all rods behaved satisfactorily. That seems to indicate that a comparatively small drop in temperature of the white-metal below some critical temperature makes a considerable difference to the cracking, due to the greater strength of the white-metal at lower temperatures. The trouble with the white-metal in vehicle engines may perhaps be relieved by increasing the amount of oil circulating so as to keep the white-metal cooler.

Lead-bronze bearings, which are giving very satisfactory results, may get them entirely out of this trouble. He did not agree with the author that it is necessary to use a case-hardened shaft with this type of bearing owing to the greater hardness of lead-bronze compared with white-metal; if the bearings are properly housed and given a suitable clearance and the lubricating oil well filtered, the amount of wear on the crankshaft with lead-bronze bearings is no more than occurs with white-metal bearings, and in some cases is slightly less.

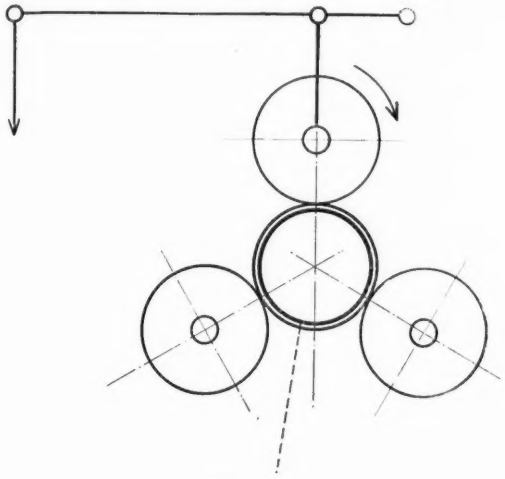


FIG. 18.

Principle of N.P.L. ring fatigue testing machine for testing liners of bearings.

In connection with the corrosion theory put forward by the author, he suggested that he should carry out tests of a cylinder liner that has been chromium-plated in the bore and that he should try nitrided stainless steel. Bare stainless steel cannot be used, owing to its tendency to seize, but this might be overcome by nitriding.

He had had some experience of a nitrided exhaust-valve steel of the K.E. 965 type for a sleeve-valve which has shown very promising results. The number of hours run with this sleeve is very limited, but it did show an extraordinarily small amount of wear when compared with other materials. This type of steel is perhaps too expensive for cylinder liners, but perhaps in some cases it may come within the bounds of commercial possibility.

Mr. A. BAILEY: On the assumption that the cause of the failure of white-metal liners was the alternating strain on the liner which the steel could withstand but the liner could not, the matter was considered by the Aeronautical Research Committee a few years ago and experiments were carried out at the National Physical Laboratory by Sir Thomas Stanton on a machine designed by him, the principle of which is shown in Fig. 18. In these experiments rings

were lined by a number of manufacturers by their particular processes, the thickness of the liner being 0.02in.

The ring under test is the central ring, and the thick line is the liner. Three rollers are placed at 120° apart, as shown, and the upper one is loaded and caused to rotate, thus rotating the specimen and producing an alternating stress which is reversed three times in each revolution. The specimen was rotated at 1000 r.p.m., *i.e.*, 3000 cycles of stress, and after 15 million cycles of stress each of them showed signs of cracking in the liners in various degrees, the variations no doubt being due to the different kinds of metal used and also to the different methods of applying the metals. A lead-bronze liner tested in the same way as the white-metal liners withstood 15 million reversals without any sign of cracking.

He thought these tests did indicate that it is most probable that the cause of the cracking is the alternating strain which takes place on the liner, and therefore probably explains the fact which the author has pointed out, namely, that very different impact pressures on the liner itself do not seem to cause any difference in the cracking. That may, of course, be due to the fact that the big end is designed to suit the particular conditions under which it works and therefore is not more strained in the case of the heavy-oil engine than in the petrol engine, which has a lighter force operating on it.

Mr. L. J. LE MESURIER: Bearing troubles are, in his opinion, confined to the high-speed compression-ignition engine only and are of little importance in the case of the slow-running type of engine, while liner wear affects all types of engine; in the large slow-running engine, however, liners have a life of anything from six to twelve years, and the problem is therefore less important. A marine engine should run without serious overhaul for the four years between Lloyd's surveys, during which period it may run for 25000 hours at a 90 per cent. load factor, the equivalent of about 12½ years for a vehicle engine at a 33 per cent. load factor running, say, 2000 hours per year.

At the present time there is probably no high-speed type of engine which can satisfactorily meet these requirements, and the difficulties and disadvantages which have to be overcome and do not appear to be insuperable are as follows:—

(1) The higher rotational speeds, 100 r.p.m. for a marine engine and 1500 r.p.m. for a vehicle engine, involve more frequent repetition of load which may induce fatigue effects in the white-metal linings of the bearings.

(2) Combustion conditions involving a much more rapid and higher pressure-rise.

(3) The lighter scantlings in the high-speed type demanded by reason of inertia effects involve higher stresses which have to be provided against by the use of special alloy steels. The distortion effects are, however, greater and there is also a relatively smaller mass of parts to absorb the shock due to pressure-rise.

He agreed that it is difficult to get reliable mass evidence as to liner wear, as the methods of measurement and of recording results vary so widely; records should be based on a time rather than on a mileage basis and wear readings should be confined to not more than 10 per cent. of the top piston-ring travel.

The figures for wear given by the author indicate a rather higher rate of wear than is usual in 4-stroke marine auxiliary engines of either air- or airless-injection type, as shown in Table I. The difference might be still greater if the high-speed engine were called upon to use the variety of fuels employed in marine engines instead of specially selected high-grade fuels.

He could hardly agree with the author that the amount of wear can be deduced by measurement of the amount of iron in the lubricating oil. His results do not appear to be supported by direct measurements of liners, which usually show that engines of widely differing combustion characteristics all have a rate of wear of about the same order.

Table I. summarises the results of maximum liner wear readings taken in two directions at right-angles at the top of the cylinder in 53 cylinders of both air- and airless-injection 4-stroke engines and indicates an average wear not exceeding 0.004in. per 1000 hours. The column giving the hours in service indicates the period during which the measurements were taken. They were 2-cylinder engines of about 12in. diameter and 50 b.h.p. per cylinder, with the exception of the engine marked "X," which was a 4-cylinder engine of 8in. diameter. The wear appears generally to be of the same order whether the

TABLE I.

Maker.	Speed, r.p.m.	No. of cylinders measured.	Hours. Minimum	Maximum	Average of all cylinders. Wear per 1,000 hours.
		Air-injection engines.			
A	400	8	10,500	18,000	0.0027
B	300	12	9,000	20,000	0.0019
B	300	8	3,000	8,000	0.0026
C	300	10	13,000	17,000	0.0037
D	300	3	5,500	6,500	0.0012
		Airless-injection engines.			
X	450	4	3,500	3,700	0.0039
Y	300	8	4,000	10,000	0.0022

engine is of air- or airless-injection type, but in certain cases individual cylinders of the same engine showed a considerable difference in wear, due, no doubt, to liner material or to differences in mechanical alignment. There are, however, no such wide variations as might be expected if the experiments described by the author gave a true indication of liner wear, and he believes that any attempt to gauge liner wear in a 10-hour test in the manner described may be entirely misleading; each test would have to be checked by actual measurements of wear, and for this purpose it would be necessary to run separate tests of, say, 500 hours' duration each, in order to produce a sufficient amount of wear to measure the small differences shown by the iron test. He would like to know how the author attempted to correlate the iron test with actual wear measurements.

Amongst the mysteries connected with liner wear he would mention the following:—

(1) The rate of wear is generally found to be 25 per cent. to 50 per cent. greater in the upper portion than in the lower portion of the liner in an opposed-piston engine, irrespective of whether the scavenge ports are in the lower or upper portion of the liner, probably due chiefly to mechanical difficulties in the alignment of the upper piston.

(2) The discrepancy in the rate of liner wear in multi-cylinder engines where each cylinder appears to be working under identically the same conditions with the same fuel and lubricating oil.

(3) The severe wear occurring on the top piston-ring grooves, particularly in 2-stroke engines, and also in some cases on the body of the piston where the piston ring butts. If this is a corrosion effect, it is difficult to see why it does not produce any effect on the piston crown or on the cylinder-liner walls above the ring travel.

Though he agreed with the author as to the probable beneficial effect of a protecting oil film, it is almost impossible to obtain such a film, particularly in a slow-running engine. To effect some improvement in this direction and also to avoid fracture of the top ring, he suggested that the top ring should be made to act solely as a scraper ring and not as a pressure-retaining ring by providing grooves across the surface of the ring to equalise the pressure above and below. By this means the ring will be allowed to float freely in the groove

instead of being subjected to a very high differential load. The ring will also serve to carry oil above the first pressure ring and will also act as a heat carrier and generally improve the conditions under which the pressure ring has to work.

Finally, as regards the material of liners and piston rings, there is plenty of evidence to show that by careful selection of material, liner wear can be enormously reduced.

Mr. A. F. Evans: He submitted that the cracking of the white-metal in big-end bearings of high-speed compression-ignition engines is almost entirely a product of detonation. The whole question of detonation does not appear to have received the consideration to which it is entitled.

Reply to Discussion

It is rather difficult to reply to the very excellent discussion, partly because so many points of view have been expressed and partly because several of the speakers have in effect replied to and cancelled each other. It has indeed been the most productive discussion I have yet heard: productive in the sense that facts and points of view have been presented by speakers of great authority. I presented in the paper a theory which I have cherished for a year, but have reserved for just such a test as this discussion has given it. On the whole it has stood the test very well and has emerged considerably strengthened thereby, while the generally accepted theory of cylinder wear by abrasion has received some very severe shocks from the evidence of speakers whose opinions and wide experience entitle them to the greatest respect. It is curious and a little surprising to me that only one speaker has referred to what I thought was the obvious moral in regard to cylinder wear—namely, to keep the cylinder barrel at a temperature above the dew point of the partial products of combustion. In this connection I am disappointed in the chemists; I had hoped that they would be able to tell us just what partial products we had to look out for and the approximate temperature of their dew points. I believe that so long as the inner surface temperature of the cylinder liner is maintained at something over 120°C., corresponding probably to a jacket water temperature of about 80° to 90°C., we should be safely above the dew point of such acids as formic acid and acetic acid, both of which, I believe, are present. On the subject of connecting-rod big-end bearing failures I am afraid we have not progressed very far, except perhaps to learn that lead-bronze is not so unkind to a relatively soft crankshaft as I had feared.

Mr. Tizard taxes me with talking loosely about boundary lubrication—a widely-used expression which nobody really understands. I must accept the rebuke; all I really mean is a very thin film—too thin to protect the surface from corrosion. With relentless arithmetic he goes on to show that if corrosion were the real cause of wear, the cylinder would almost fade away while watching it. I have a great respect for arithmetic—under severe control—but my experience is that the answer is often merely a product of the initial assumption, and I cannot agree with the assumption that the entire surface need be oxidised at every cycle. In the terms of which Mr. Tizard speaks our smooth-cylinder bore must be regarded, not only as rough, but almost mountainous, and it may be that only a few of the projecting peaks and not the whole surface are attacked at each cycle. Mr. Tizard suggests that corrosion, and what I may call for short, corrosive wear, occurs only at starting up. I believe that it occurs so long as the inner surface of the liner is below the dew point of the products of partial combustion, which under the high pressure ruling in the cylinder may be well over 100°C. With regard to the wear at the bottom of the stroke, I do not suggest that this is caused by corrosion; the wear here is relatively very slight and I exaggerated it in my diagram merely to call attention to it, and, such as it is, I am quite prepared to attribute it to abrasion alone.

Dr. Dunston refers first to the effect of wave motion in the connecting-rod as a cause of big-end failures—I also referred to this in the paper, but such evidence as I have acquired does not bear it out. Prolonged tests have been made with the engine running at the critical period of the rod without revealing any trouble; furthermore, as I pointed out in the paper, engines with open-type combustion chambers should be far the worst sufferers on account of their much more rapid rate of pressure-rise—in practice they suffer no more than others. With regard to cylinder wear, I had hoped that Dr. Dunston would have been able to throw some light on the question instead of merely brushing it aside. I cannot claim to be a chemist, but, as a mere observer, I can state that certain acids, known even to a layman like myself to be present in the products of partial combustion, can and will attack through a thin oil film and that the surface does not need to be chemically clean to render it susceptible. Speaking as a chemist, Dr. Dunston describes the partial products to which I refer as " entirely unknown," but having an acrid smell. We have taken many samples of these products and many of them have been identified as quite well-known substances. Dr. Dunston goes on to say that engines running in his laboratory under prolonged heavy load tests show from one-tenth to one-quarter of the wear found in service on the road: precisely—this is exactly what I should expect; the laboratory engines are running with hot liners. Other speakers in the discussion have disposed of the belief that dust is the cause of wear, and I would add that some of the worst cases of wear I have come across have been in marine engines, where dust is absent, but cold circulating water all too abundant. Again, Dr. Dunston remarks that " he hardly thinks that the nature of the fuel has been stressed so much as it should have been." In speaking of the " nature " of the fuel I presume he must mean its chemical nature, but if, as he contends, chemical action plays no part, then why stress this point?

I disagree with Mr. Tom Thornycroft with regard to big-end bearing failures; I do not think that workmanship or fitting are to blame. The experiment has been tried of exchanging complete connecting-rods from one make of engine to another without affecting the result. In regard to cylinder wear, Mr. Thornycroft points out that engines running with a low load factor show much greater wear than those which are heavily loaded. This is just the sort of confirmation I had hoped for. The former are running cool and probably below the dew point of the partial products and the latter fairly hot. His evidence as to the effect on wear of the introduction of water to the cylinder also tends to confirm my theory, for, as I had mentioned, the corrosion would be the more intense when the partial products could find water to whet their appetites. Finally, his evidence as to the effect of air cleaners on engines in use in the Sudan goes far to disprove the theory of abrasion. I am most grateful to Mr. Thornycroft for giving me added confidence in my creed—all his evidence discloses exactly what I would hope and expect to find.

I should like to congratulate Mr. Duff most sincerely on what appeals to me as one of the prettiest pieces of carefully reasoned and beautifully executed research I have ever heard of. If I have accomplished nothing else this evening, I shall feel quite satisfied in having brought Mr. Duff to his feet. All that Mr. Duff has told us falls into line with the theory of corrosion as the chief cause of cylinder wear, and his beautifully staged experiments fit perfectly. Incidentally they are a severe commentary on what the average motor-car manufacturer advises us as to the handling of his products. On two small points only I would like to question Mr. Duff's figures. He reckons the dew point at 90°C.; such information as I have been able to screw out of reluctant chemists places the figure at nearer 120°C., taking into account the pressure obtaining in the cylinder. With all respect I am tempted to suggest that both his estimates of the temperature of the inner surface of the liner and of the dew point are too

low—this, however, is perhaps academic and certainly does not affect his results or his reasoning.

I am very interested in what Mr. Chorlton has told us about his experience with large gas engines. With these large slow-speed engines it is, of course, possible to spread the oil all round the piston in a manner not practicable in small high-speed engines, and I can well believe that he was able to get better protection of the liner. With regard to big-end bearings, his remarks also are most interesting, more particularly his contention that an oil film should be maintained between the bearing shell and the rod. I, too, have contended the same thing, in order to spread the load hydraulically.

I would like to congratulate Mr. Boerlage on the very pretty method he has developed for measuring cylinder wear over quite short runs of half-an-hour or so. His method is, I think, going to prove of great value, and I endorse whole-heartedly his neatly expressed conclusion that wear can be smelt. It is the products of partial combustion which account for the acrid smell of an engine's exhaust, and it is they, I contend, which account for the bulk of the cylinder wear we tolerate to-day. I feel that the research work which Mr. Duff and Mr. Boerlage are now undertaking is likely soon to nail down the cause and point the solution to a problem which has vexed us for a generation.

Mr. Pye takes me to task for describing cracking of the white-metal in big-end bearings as normal in aircraft practice. Perhaps that is too sweeping a statement, but it is fairly common, my point being that in aircraft practice it is not viewed with the same horror as in the commercial-vehicle world. I agree that the cracking must be due to some flexure, but in heavy-oil vehicle engines it starts almost invariably from the centre right under the shank of the rod—at the stiffest point—whereas in petrol aero-engines it occurs anywhere and usually at the sides. On the question of cylinder wear, Mr. Pye's evidence certainly tends to fortify my theory and to dispose of that of abrasion.

I am very much interested in Captain Wilkinson's remarks, both as to stiffening the eye of the rod and as to the effect of lowering temperature. I agree that beyond a certain point additional stiffening does not help at all. As regards temperature, in general, heavy-oil vehicle engines are provided with a very brisk oil circulation, and the oil is kept fairly cool; such engines, however, are used in all sorts of vehicles, some with well-cooled sumps and others so shielded that no air reaches them, yet the trouble appears to be confined to certain makes, not their application. Two makers, who are immune, supply engines to be fitted into all sorts and kinds of vehicle, and the cooling conditions must vary widely. With regard to cylinder wear, we have not ourselves tried out a nitrided stainless steel liner, but I have seen one which, after some 400 hours' running, showed no measurable wear; this, of course, was what I had in mind as one of the lines of attack. I am also very interested in Captain Wilkinson's remarks about lead-bronze bearings—I feared that these would punish the crankshaft too severely and I am very relieved by what he tells us.

We supplied some of the sample white-metal lined bushings for the tests Mr. Bailey speaks of, and my recollection of the tests is that there was not much to choose among the various white-metalled samples, but that the lead-bronze stood out head and shoulders better as regards cracking and adhesion.

Mr. Le Mesurier is, I think, in agreement with me on most points. As regards the failures of connecting-rod big-end bearings in high-speed engines I agree that such may be expected; I am surprised rather that many are immune despite conditions which, so far as I can deduce, are not favourable. With regard to cylinder wear, the figures Mr. Le Mesurier quotes strike me as unusually good. I could quote, *per contra*, an equally comprehensive group of figures supplied me by one of the large shipping companies in which the average rate of wear is nearly three times that given by him. The method of determination of wear by measurement of the iron in the lubricating oil has been developed to a

high degree of perfection by Mr. Boerlage and others at Delft, and, as Boerlage has shown in the discussion, quite consistent measurements of wear can be taken in less than one hour's run. In the experiments I quoted, the method was less exact than Boerlage's, but readings were taken over periods of ten hours. I gave those observations as a matter of interest, they covered a very large number of 10-hour tests totalling several hundred hours, and they were remarkably consistent between themselves. I would not, however, attempt, and I would not advise anyone else to attempt, to generalise from them. Mr. Boerlage has already drawn attention to the moral to be drawn from them, namely, that what he describes as " half-combustion " is the prime cause of cylinder wear. This may be due to the fuel entirely or to the combustion-chamber design. In the tests I quoted a rather poor fuel was used, and the obvious inference is, I think, that one combustion chamber could digest it, the other could not. Had a better fuel been used, then probably the wear would have been small in both cases; had a worse been used, then I should expect both tests to show up badly. The fuel used in these tests was a fair average sample of what is obtainable in bulk, and what the high-speed oil engine will probably have to use when we can no longer afford to coddle it with specially selected fuels.

The first of Mr. Le Mesurier's mysteries is new to me; I certainly cannot attempt to explain it. The second is, I think, not inconsistent with the theory of corrosive wear, for this must depend to some extent upon just how clean the surface is wiped by the rings, and I should expect a variation not only between different cylinders, but also round the circumference of each cylinder as, indeed, we generally find. With regard to the third mystery, in nearly all cases of severe ring-groove wear which I have examined, the cause has been due to the building up of carbon behind the top ring, thus forcing the ring out till it is bottle-tight in the liner, so causing it to drag heavily against the lands in the piston. It is, I suggest, a case of hammering rather than of wear. Mr. Le Mesurier's suggestion of using a top ring grooved on the working face appeals to me as a thoroughly sound one, and I should much like to see it tried. Finally, I quite agree with Mr. Le Mesurier that the material of the liner counts for much, but I suggest that the material should be one which will resist corrosion rather than abrasion, and that surface hardness is not the prime factor.

I cannot accept Mr. Evans' suggestion that all big-end troubles can be explained by detonation. The phenomena of detonation in heavy-oil engines is receiving a great deal of attention, but its elimination does not cure the big-end trouble.

COMMUNICATED

Mr. F. R. BANKS: In regard to big-end trouble, does the author think that the following theory " holds water "? The big end of the connecting-rod of the oil engine is subjected to considerably higher maximum pressures than its counterpart in the petrol engine, and if such a pressure were sustained throughout the working cycle, it would no doubt cause a relatively high rate of wear on the bearing, but it would not give rise to cracking of the white-metal. Since this pressure is not, in practice, sustained throughout the working cycle, but only occurs over a crank angle movement of a few degrees, it transmits a " shock loading " to the big-end bearing which causes flexion of the bearing shell and therefore of the white-metal. The flexion is at fairly high frequency due to the engine speed, and the white-metal, when subjected to this, together with the effect of temperature, will show a very poor " fatigue " factor. Therefore, it eventually cracks. His theory was that it may not be so much due to the maximum pressure or even the rate of pressure-rise, both of which will have different values in different engine designs (as shown by the author in Fig. 10), but that it may be due to the relationship between the peak pressure and the top dead-centre of the crank.

That is to say, the connecting-rod big end, on approaching the top dead-centre position is bearing on the top half of its shell, but at or about the centre, assuming no explosion forces, the big end is violently jerked on to the bottom half. Now, if the delay period and rate of pressure-rise are such that the pressure peak occurs well after top dead-centre position of the crank, is it not possible that the connecting-rod assembly comes up against the bottom half of the big-end bearing, and is then slammed back against the top half of the bearing again, due to this retardation of the peak pressure position, greatly increasing the " shock loading " factor? Admittedly the bearing clearances are relatively small, but it is the alternating stress which also counts.

There might conceivably be less cracking of white-metal, for instance, in the extreme case of an engine which has a rate of pressure-rise so high that it is practically a vertical line on the diagram, with a high peak, but coinciding with the period at which the inertia forces are tending to drag the connecting-rod assembly from the top half of the big-end bearing, and so assisting in cancelling out the " slamming " effect.

Going to the other extreme and taking the case of the " Comet " type of combustion-chamber design, which appears to be the nearest approach to petrol engine conditions, he was under the impression that the engines employing this particular system are among the group of which the operating speed (r.p.m.) is about the highest in present-day use; therefore, the inertia forces on the connecting-rod assembly would also be fairly high. In Fig. 10 the pressure peak shown for this design is perhaps further removed from the top dead-centre position than any of the others.

The author's " corrosion attack " theory accounting for cylinder wear is the most hopeful suggestion put forward for some time. He had often noticed the line of corrosion, which formed very rapidly at the top end of the bores of some single and multi-cylinder experimental engines with which he was concerned. He had come to the conclusion that although dilution of the lubricating oil has been blamed for a large amount of trouble in this connection, it has little bearing on the question.

The only exception which perhaps brings some element of doubt on the author's theory is that of the old petrol/paraffin engine, which was a bad offender as regards cylinder wear and dilution trouble. However, here again the author's theory has a sound basis, since most paraffin engines usually work for quite long periods with relatively inefficient combustion due to changing over from petrol to paraffin too soon, or " idling " the engine for extended periods on paraffin. This would cause products of partial combustion to settle on the exposed surface, and the rate of wear would be exceedingly high.

Mr. O. W. J. Watson: The high-speed compression-ignition engine presents certain problems which can only be satisfactorily solved by extensive research; there are too many variable factors to enable the solution of these problems to be found by comparing a number of different engines incorporating many differences in design. The very characteristics of this type of engine are such as to accentuate, and show up very quickly, any weaknesses in design, such as the fact that it is possible to apply full load immediately upon starting up from cold; the petrol engine, on the other hand, cannot take its full load until it has received its preliminary warming up.

He thought it was very unlikely that a universal remedy will be found for such troubles as those with big ends; each case will have to be dealt with on its merits. At the present time there are no two engines alike in all details, and what may appear at first sight to be a trivial difference, may possibly be the cause of failure *in combination with* other features of the same engine; it must be realised that each separate feature has its own effect upon the performance of the engine.

In connection with the author's reference to chemical action in a cylinder due to certain constituents of the fuel, he had noticed that, if an engine which has been in service is opened up overnight, in a very short space of time considerable oxidisation takes place.

In conclusion, can the author say whether he has observed any tendency to high instantaneous pressures, more especially when the engine is suddenly accelerated from idling?

Mr. E. C. Ottaway: He felt that the author in propounding the theory of corrosion, has rather stressed this to the exclusion of other factors which undoubtedly have a bearing on the matter. It may be agreed—particularly in view of the results put forward by Mr. Duff—that corrosion is probably the main factor, but, as a result of a very large number of service tests, it has been conclusively proved that very considerable variations in cylinder wear may be effected by changes in piston design and cylinder material, in the latter case, as far as can be judged, without serious alteration to the corrosion-resisting properties of the iron.

The author's statement that the rate of wear appears to be independent of the speed of revolution has been found to be true in so far as test-bed results are concerned, but is subject to modification when the wear is considered on a mileage basis, under which conditions it can be shown quite clearly that the rate of wear does depend on the average number of engine revolutions per mile.

He agreed, too, that the piston material has no effect on cylinder wear, but, at the same time, he thought, to present the case fairly, it can be shown that considerable improvement can be effected by a suitable cylinder iron. In this connection they had found that by increasing the phosphorus content of the iron from 0.2 per cent. to 0.6 per cent. with no other change, the cylinder wear can be improved by approximately 30 per cent. to 40 per cent., the increase in phosphorus content slightly improving the corrosion-resisting qualities of the iron, but the major difference being in the larger area covered by the hard phosphite in the matrix of the iron.

The author's statement that he can find no evidence to show that the rate of wear is influenced appreciably by the service on which the engine is operated can be disproved since they had definitely found that the rate of cylinder wear is considerably increased by frequent stopping and starting, and to a further considerable extent when the stopping and starting allows the engine to become cold between the periods of running. This latter fact entirely supports the corrosion theory.

On one particular type of engine, when the load factor was increased by raising the rear-axle ratio, the cylinder wear was actually improved when recorded on the mileage basis and the oil consumption characteristics of the engine were considerably better when taken over a long mileage, this fact again serving to show that the revolutions per mile do affect the cylinder wear, whereas the load at which the engine is working is relatively immaterial.

It has been generally found, when running an engine on the test-bed continuously under full or high percentage load, that the cylinder wear is very small indeed, and it is difficult to reconcile this fact with the high rate of wear recorded on marine engines, and he could only assume that they are run with excessively cold water jackets. It must not, however, be deduced from the wear experiments recorded in respect of these engines that cylinder wear is not improved under constant-load running conditions.

During the past two years they had found from a certain rather restricted experiment that chromium-plated cylinder bores give an extremely low rate of wear, but it is difficult to make a commercial proposition of this process owing to the difficulty of obtaining a perfectly even thickness of chromium deposit. Unless such a deposit can be obtained, it is unlikely that this method will prove commercial, since the deposit itself is practically unmachineable, and can only be

finished by honing, which will not remove sufficient stock to even out the irregularities of the deposition process. To grind is inadmissible, owing to the relatively small thickness of the deposit.

From the above facts it will be seen that a good case has been made out for other factors than corrosion having some bearing on the matter, but, at the same time, they also support the author's theory of corrosion as being probably the major factor.

Mr. C. SMITH: The author's discovery of a band of rust in the bore of a cylinder which had blown off during a test gives ample food for thought. The presence of rust was assumed to be caused by chemical action of the products of combustion acting on the bare iron. If such was the case, it might be possible to prevent such action by either mechanical methods or control of undesirable products. He was of opinion that it should be overcome by mechanical means, and submitted the following suggestions:—

(1) By the use of a piston with an inverted skirt, sufficiently long to shield that part of the cylinder bore usually affected during the early stage of combustion. This would call for some modification of the cylinder head to accommodate the suggested skirt.

(2) By High-pressure injection of lubricating oil into the cylinder at top dead-centre, at a point about in line with the top ring, an annular groove being machined in the cylinder bore to ensure even distribution. The method of feeding the oil could be effected by a high-pressure pump similar to fuel-feed pumps used on compression-ignition engines. Such a pump would make it possible to control both quantity and timing to the desired requirements, *i.e.*, such as load and speed. By this method, piston and gudgeon-pin lubrication would be entirely independent of crankcase feed, and baffles, scraper rings, etc., would need to be provided to prevent oil entering from the bottom. A further advantage could be gained by providing an annular trough at the base of the cylinder which could be fitted with a drain to prevent crankcase dilution and carbon entering the sump oil.

Mr. J. W. ROBERTSON: As a tentative explanation of the peculiarly epidemic trouble of cracked big ends in compression-ignition engines, the physical properties of the tin constituent in the white-metal seem to offer at least a possible hypothesis.

Tin shows a maximum ductility at about 100°C., and becomes increasingly brittle at lower temperatures, until, at 18°C., the change to its allotropic form, "grey tin," commences. This change does not proceed with disintegrating effects until considerably lower temperatures, when the "Tin-Pest," experienced in organ-pipes, during cold winters on the Continent, occurs.

Nevertheless, the fact remains that tin is metastable at ordinary winter temperatures, and, whereas the most brutal of petrol-engine operators seldom subjects the big ends to maximum load conditions until their temperature has risen out of the danger zone, the compression-ignition engine immediately administers the worst possible treatment to these parts at a time when their temperature is considerably below 18°C.

In reference to the author's theory of cylinder corrosion, he would like to know whether he has any test results from the chromium-plated liners, with which at least one large firm has been experimenting recently.

In this connection, he was at present fitting stainless steel sleeves of about 300 Brinell hardness to an experimental sleeve-valve two-stroke engine, and looks forward to an interesting comparison between them and the previous cast-iron ones.

Mr. R. STANSFIELD: There are many experimental data which make it difficult to accept the corrosion theory as regards liner wear. For instance, in small high-speed engines it is frequently found that the wear is at least twice as great on one side as on the opposite side at the top of travel of the top ring.

If corrosion were the major factor it seems reasonable to suppose that the wear would be more evenly spaced around the cylinder circumference. They had run a petrol engine in a series of 50-hour runs at 1,500 r.p.m. for 1,550 hours with a jacket temperature of 212°F. and found the cylinder wear to be 0.0005in. at the top of the travel, the wear on the rest of the bore being too small to measure. The wear represents a loss of metal of about 0.5 gm. for the cylinder walls and 0.6 gm. for the rings. Two other engines, one in a car and one on the bench, showed cylinder wear of 0.004 in. in the first and 0.001 in. in the second after 500 hours' running; in every case no evidence of corrosion could be found. Measurements on a compression-ignition engine after 650 hours showed a wear of 0.009 in. and another a wear of 0.005 in. after 400 hours' running.

He could not help thinking that the author's estimation of wear from the amount of iron in the lubricating oil based on only 10 hours' running is open to serious error. Apart from possible measurement error, variations in the viscosity of the lubricating oil might affect the amount of iron returned to the collecting point. Again, the differences observed between one combustion-chamber type and another as regards iron in the used lubricant also might be caused by the effect of design on temperatures, and temperatures on the interchange of the lubricant, and not necessarily by actual wear differences.

A slow-speed horizontal compression-ignition engine was run some time ago for 400 hours at full load in a series of 50-hour runs on different fuels, and it was found that liner measurements could not be taken accurately enough each 50 hours to have any meaning, but the ring weight losses varied over a ratio of 3 : 1 depending on the amount of adventitious matter which could be centrifuged in several successive treatments from the different fuels used. The ring weight loss was not a linear function of the amount of abrasive present in the fuel, but increased very rapidly from the cleanest oil obtainable when small additional abrasive was present. As the amount of abrasive increased the rate of increase of wear was reduced, and a value was soon reached above which very large additions of abrasive produced no important effect.

After 400 hours' running it was possible to make reasonably accurate measurements of the liner, and it was found that for a total ring weight loss of $17\frac{1}{2}$ gm. the loss of metal from the liner was about 25 gm., taken over the length traversed by the rings. The relation between loss of ring weight and the amount of abrasive which could be extracted from the fuels by repeated centrifuging is shown in Fig. 19.

With regard to Mr. Duff's curve, Fig. 14, showing the relation between wear and temperature, might not the variation in piston clearance between the cold and the hot engine have a possible effect? He would also like to know whether the viscosity of the lubricating oil was adjusted at each engine temperature so that it remained unchanged. There are indications that wear increases rapidly, due to inadequate and uneven oil-flinging when the lubricant viscosity rises above a certain amount, even though the cylinder-jacket temperatures are retained constant. A haphazard and localised supply of viscous oil may well give much worse lubrication than a copious feed of kerosene.

Assuming that it is proved that corrosion is operative at low temperatures, it is interesting to combine the curve of Fig. 19 with a curve of the type shown by Mr. Duff.

At low temperatures the corrosion factor is high, and the suggested added effect of abrasive (Fig. 20, curve A) does not increase the wear by more than 40 per cent. for a small amount of abrasive. At high temperatures the corrosion effect is considerably reduced, but the same added wear (curve B) due to abrasive means an additional wear of about 250 per cent. above the corrosion amount, the total wears for the two cases selected being approximately as $2\frac{1}{2}$: 1. Curve B does not allow for the possibility that a given amount of abrasive may have a greater wearing effect when the engine is hot and the lubricant thin, so that it

may have to be raised to some such position as curve C to allow for this, still further increasing the importance of the abrasive factor.

The tests on the compression-ignition engine referred to indicated that the steep part of the abrasive effect was passed with quite small quantities of foreign matter, and he suggested that further evidence is required to determine whether both corrosion and abrasion may not occur together, and whether factors assisting one may not tend to reduce the other, thus bringing wear values into fairly close agreement for all engines of a given type under widely varying conditions of commercial use.

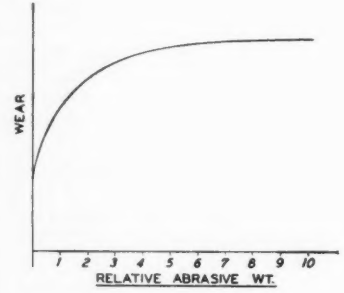


FIG. 19.

Relation between loss of ring weight and amount of abrasive in lubricating oil.

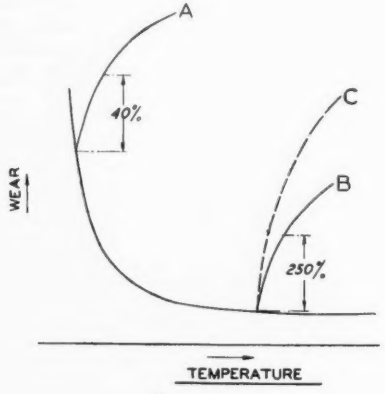


FIG. 20.

Lt.-Col. L. F. R. FELL: During the war he gave particular attention to the difficulties experienced with connecting-rod big ends due to white-metal cracking on the various types of aero engines, and the conclusion at which he had arrived was that so long as white-metal is employed the trouble is always likely to occur, and that the remedy lies in the discovery of some bearing material having better mechanical properties than white-metal. He thought that the fact that some engine makers seem to suffer acutely, while others appear to be free from connecting-rod bearing cracking, is mainly due to the varying " coefficients of optimism " of those with whom Mr. Ricardo has discussed this matter. Bearing troubles are often of a curiously epidemic nature. Comparative immunity from difficulty might be experienced for a time, and without any apparent change in

design, materials, workmanship, or operation, cracking suddenly becomes prevalent.

In his opinion the failures have little to do with lubrication and are purely mechanical. Evidence is conclusive that white-metal fails in the big end opposite the point of greatest rigidity in the connecting-rod structure. In consequence a design which might appear at first sight to be very robust and likely to stand up proves to be very disappointing in actual service, due to the fact that the load is concentrated in the crown of the bearing instead of being distributed over a considerable arc. The design of the big end should therefore aim, not so much at rigidity, which must result in the addition of weight where weight would be undesirable, but at obtaining equalised pressure over as large an area of the crown of the bearing as is possible. This could probably be more readily achieved by increasing rather than decreasing the flexibility.

In Fig. 10 the author shows a very much higher maximum pressure for the open-type combustion chamber than for the other systems. It is suggested that these high maximum pressures are not inseparable from the use of the open combustion-chamber design, and the results which have been obtained—notably by Mr. Taylor at the R.A.E.—indicate that reasonable maximum pressures are not inconsistent with low fuel consumption and high b.m.e.p. This is also confirmed by the Beardmore experiments.

He agreed with the author that there are other influences at work than abrasion to cause wear. In this connection he had carried out experiments on a steel cylinder using duralumin rings in a duralumin piston, and when wear of the rings in their grooves had been eliminated by introducing steel shims, it was noted that cylinder wear was still pronounced, though the working surface of the duralumin rings stood up very well.

Mr. C. B. Dicksee: The lack of consistency in the results obtained by different manufacturers from similar types of bearings is, indeed, the most puzzling feature of the compression-ignition engine, and it is a curious fact that tests carried out by continuous running at top speed and full load on the dynamometer give much more favourable results than those obtained in service on the vehicle.

Experience seems to show that passenger vehicles operating on city services have trouble to a more marked extent than either long-distance passenger vehicles or goods vehicles, and it would appear that the continual getting away under load may be a factor which influences the case. These vehicles do not have an appreciably greater number of cold starts than do vehicles in other services, so that although it is possible that some damage is done when starting from cold, it cannot provide by any means the whole story.

With regard to the use of floating bearings for the connecting-rod, he could not agree with the author's statement that white-metal can be used for these bearings without any risk of cracking, as he had recently examined a set of such bearings, and instead of the cracking taking place over an arc of about 90° under the crown of the rod, as is usual with the normal arrangement, the cracking extended for the entire 360°.

With regard to the cylinder-liner wear, he most emphatically disagreed with the author's statement that service and engine speed have no bearing on the rate of wear, as experience under actual service conditions shows very definitely that the cylinder wear is greatest on city services and least on vehicles which operate for long distances daily. It certainly appears to be true that the piston material itself has little or no bearing on cylinder wear, and that the piston rings themselves are the culprits, indirectly at any rate. It has frequently been observed that during extended bench tests the wear on the cylinder has been almost negligible, whereas the same engine placed on the road will show from 3 to 4 times the rate of wear in the same period of time, even although the average

engine speed and load must have been appreciably less than that at which the bench tests were run.

He was entirely in agreement with the author that corrosion rather than abrasion plays the major part in so far as wear is concerned, and he had almost invariably observed that on removing the cylinder head from an engine after test, patches of rust are discernible on the cylinder bores, these being in evidence even in cases where the cylinder head has been removed while the engine is still warm. It is, of course, necessary to remove the head without having previously turned the crankshaft, otherwise the traces of rust will be removed. The appearance of such rust inevitably means the removal of a certain amount of iron, and it stands to reason that the more often this condition arises the more rapid the cylinder wear becomes. This offers an explanation why engines which are run only intermittently suffer far more from cylinder wear than do engines which are run continuously, and confirms the tests reported by Mr. Duff. To his mind, there is no need to look for obscure products of partial combustion to find the cause of corrosion. Carbon dioxide in the presence of moisture is one of the most active rust-producing agencies, and these two are the normal products of complete combustion.

With regard to the author's deductions from the amount of ferrous material found in the lubricating oil in two different types of engine, from intimate knowledge of these two types he would state that no difference has been found in the cylinder wear under actual service conditions, whereas from the inference drawn by the author, it should have been some three or four times as great with one of the engines. It would appear, therefore, that such tests are of little value for drawing deductions as to relative cylinder wear.

Reply to Written Communications

Mr. Banks' theory as to the cause of connecting-rod failures will apply only when the inertia forces on the piston exceed the normal compression-pressure, a condition which seldom applies in a compression-ignition engine. I suspect, however, that he has taken this fully into account, and that I have misunderstood him. I am grateful to Mr. Banks for his support of my corrosive wear theory, and, as regards the petrol-paraffin engine, I agree that the comparatively heavy wear often found in this type of engine may be accounted for largely by the relatively long periods of running under conditions of very poor combustion.

I quite agree with Mr. Watson as to the difficulty and danger as regards the connecting-rod bearing problem of comparing results from different engines, and that is why I refrained from being dogmatic or even adventuring any conclusion. I merely laid down the facts as they have come to my notice in the hope that discussion would throw more light on them. With regard to high instantaneous pressures after idling, certainly the maximum pressure is somewhat higher than normal, but nothing like so much higher as the heavy knocking so often heard would imply. Knocking appears to be dependent on the rate of change of pressure and quite independent of the actual pressure itself.

Of all the published data I have examined on the subject of cylinder wear, those of Mr. Ottaway appeal to me as the most reliable, and I have the profoundest respect for his observations. If I appear to disagree with him in certain respects, that is due rather to the fact that the observations on which I have based my arguments roam over a wider field than vehicle engines. Mr. Ottaway accuses me of having stressed the theory of corrosive wear to the exclusion of other factors. To this I must plead guilty, but I wanted to concentrate discussion on this factor in particular, and therefore gave it all the prominence I could. I do not suggest for a moment that is the only one. Both Mr. Ottaway and Mr. Dicksee have pounced quite rightly on my remark that the service in which the engine was used had little influence on the rate of

cylinder wear. I am to blame, I am afraid, in not having made quite clear what I meant. I was referring in this connection to abrasive wear and was emphasising the point that whether the engine was used in road service where dust and grit are plentiful or in marine service where they are entirely absent, the rate of wear is much the same under similar conditions of temperature. I quite agree with both Mr. Ottaway and Mr. Dicksee that it differs widely under different conditions of service in the sense of load factor on the road, or on the water for that matter. The difference here—namely, worse wear under cooler or lighter load conditions—supports the theory of corrosive wear, as Mr. Ottaway has pointed out.

I quite agree with Mr. Smith that some mechanical means should be found for dealing with corrosive wear, and in this connection I am attracted by Mr. Le Mesurier's suggestion. With regard to the two suggestions he puts forward:

(1) I am afraid that the inverted skirt will behave like a too-deep top land, namely, build up with carbon until the piston becomes bottle-tight and eventually seizes.

(2) High-pressure oil injection should certainly help, but I am afraid will involve rather a complex and expensive arrangement.

Mr. Robertson's suggestion that the tin in the white-metal will not stand pounding at low temperatures is new to me and very interesting. I should like to know more about this. I have no experience of chromium-plated liner; any experience with this should be most valuable. I have not as yet been able to find any stainless steel which will not tear under the action of the piston rings, but I have seen excellent results from a stainless steel sleeve nitrided to give the necessary protection against tearing.

I think that I have dealt already with the points raised by Mr. Stansfield in my replies to Dr. Dunston and others. Mr. Stansfield's bench tests were, I note, carried out with the jacket water boiling, under which conditions there should be little or no corrosive wear. I am not at all surprised that the wear varies round the circumference of the cylinder; neither cylinder bores nor rings are so perfect that the oil will be squeezed out equally all round the circumference, and a very small difference here should affect the corrosive wear enormously. We also have made prolonged tests with the load varied automatically, and at frequent intervals, from nearly full to no load, without producing wear comparable to that found on the road, but though the load was varied the temperature remained high. As to the determination of wear by the amount of iron found in the oil, I would refer Mr. Stansfield to Mr. Boerlage's contribution to the discussion; Mr. Stansfield says that ten hours is nowhere near sufficient to obtain an accurate reading, Mr. Boerlage finds one hour ample! When dealing with Mr. Duff's contribution, Mr. Stansfield appears to accept the theory of corrosive wear and to suggest that it may be the main factor at low temperatures and abrasive wear the main factor at high temperatures. With this I agree wholeheartedly; in fact, it is the point I have been trying to make.

I heartily agree with Colonel Fell's remarks about big-end failures. I am accustomed to reckon with the "coefficient of optimism," and I think I have made adequate allowance for this factor, which often bulks very large. I appreciate, too, the factor of epidemics, though I have never been able to understand why wholesale epidemics of mechanical disease should break out suddenly and then die down without any apparent rhyme or reason, and without any remedy being found. I have watched this happen again and again. I am very much inclined to agree that we have been overdoing the stiffness of the big-end bearing, and that a little more flexibility is what we should aim at. With regard to Fig. 10, I was comparing engines of the size used in commercial vehicles, *i.e.*, between 4in. and 5in. bore. In such engines it does not appear possible to combine the open type combustion chamber with low maximum pressures. I quite agree, however, that with cylinders of the order of 8in. bore,

as in the case of the Beardmore and R.A.E. engines, this no longer applies. I am very glad to hear of Colonel Fell's experience with duralumin rings in a steel cylinder; this is yet another pointer.

It is curious that heavy-oil engines should suffer more with Mr. Dicksee's fleet when pottering about in dense traffic than when running really hard; all the more so since with petrol engines the reverse is usually the case. With regard to floating bushes, Mr. Dicksee's remarks refer to an experimental bush made up of three separate segments. I have never been able to get such a bearing to stand up at all, and I am not in the least surprised to hear that the white-metal cracked all round. Once a floating bush is split, the conditions are altered entirely. With regard to liner wear, I quite agree that this differs greatly under different conditions of usage on the road, as indeed is to be expected if corrosive wear were the chief factor. My remark was *apropos* of abrasion and was directed rather to the more general question of the comparative wear as between, say, marine and road service. I am glad to hear that Mr. Dicksee agrees with me as to corrosion being the major factor, but I think we must look rather further afield than carbon dioxide, for I understand that the thinnest of oil films will protect against this, while some of the partial products will sting even through a protecting oil film. Finally, as to the observations as to wear from the iron found in the lubricating oil, I would like to refer again to my reply to Mr. Le Mesurier, in which I emphasised that it would be most unsafe to generalise from these tests.

EXTRACTS FROM THE AERONAUTICAL & MISCELLANEOUS NOTE-BOOK (ca. 1799-1826) OF SIR GEORGE CAYLEY*

(NOTE.—Until recently it was believed that Sir George Cayley's note-books had been lost. In 1927 Mr. J. E. Hodgson, the Honorary Librarian of the Society, learnt that a quantity of miscellaneous manuscript papers were in existence in the home of the Cayley family, and permission was obtained to sort out from such papers matter bearing on Cayley's aeronautical and other engineering or technical labours. Among them was the Note-book, which will shortly be published in full by the Newcomen Society, by kind permission of Sir Kenelm Cayley.

It has been edited with notes by Mr. J. E. Hodgson, and will include, in the form of an appendix, a list of the Cayley technical papers. With the concurrence of the Council of the Newcomen Society sections of the Note-book dealing with Sir George Cayley's aeronautical researches, the most important part of the manuscript, aree printed below. They show clearly how well deserved is the tribute implied in regarding Cayley as the "Father of Aeronautics," a tribute paid to him both in this country and abroad. In their authoritative Histoire de l'Aeronautique, C. Dollfus and H. Bouché wrote: "La plus haute figure technique, dans le premier tiers du XIXe siècle, est celle de Sir George Cayley, *le veritable inventeur de l'aéroplane.*" The italics are the editor's.

Recently the Society has founded, at the request of the Air Ministry and through the generosity of its President, Mr. C. R. Fairey, the British Gold Medal for Aeronautics. One side of this medal incorporates a portrait of Sir George Cayley and a drawing from his Note-book of the first model aeroplane with which he experimented in 1804.—EDITOR.)

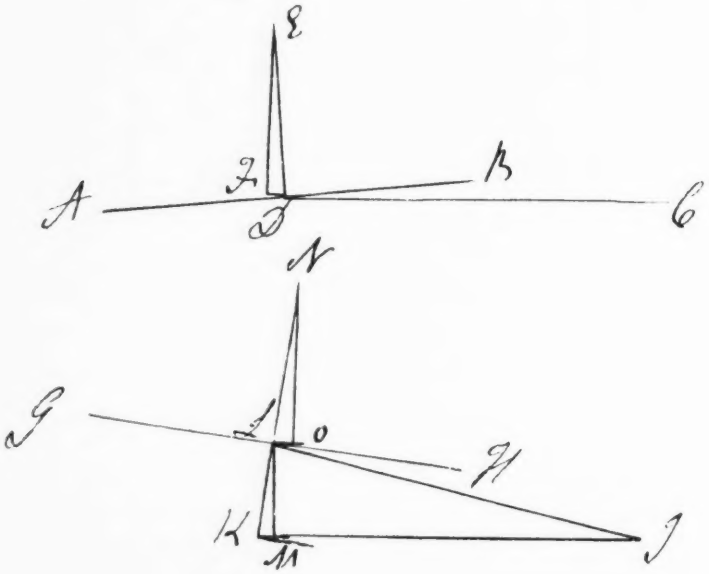
AERODYNAMICS OF BIRD-FLIGHT

If birds when in that act of flying, which may well be called skimming, oppose their wings to the horizontal current of the air in any given angle, say for example that of the tenth part of radius, and that the resistance upon the wings is sufficient to support their weight when in this position, and if (when the previously acquired motion be expended and the wings must be again waved in order to prolong the flight) it be supposed necessary that they should be moved with such a velocity (when turned obliquely in the *same angle* from the wind) as to continue the resistance the same in order still to support the weight, I say it will be necessary for the wing to be moved perpendicularly downward with a velocity bearing the same proportion to that of the horizontal current of air that double the sine of the given angle does to radius, and therefore in this case must equal one fifth of the velocity of the wind.[1]

* Published for the Newcomen Society by W. Heffer & Sons Ltd., Cambridge, 7/6 net.

[1] Mr. J. L. Nayler, of the National Physical Laboratory, has pointed out that Cayley uses "resistance" indiscriminately for what is now termed "lift and drag," and assumes that the resultant is normal to the wing.—[ED.]

Let A B be a section of a wing opposing the current of air C D, and let D E represent the pressure produced by it, then E F will shew the whole force applied to support the gravity of the bird, and D F the quantity of retarding power which for a certain time the momentum of the bird overcomes. In this case if F E be equal to half the weight of the bird (each wing bearing equally) it will neither rise or fall, but continue its horizontal motion till the retarding force D F have diminished the velocity of the current D C, the force F E will not equal half the weight of the bird. The wing must now be waved in order to continue the horizontal motion and as it is necessary to gain an accelerating power equal to the retarding one that will take place the next cessation, the position of the wing must be such as to receive the impulse from the air in some measure in an opposite direction. I have supposed it in this case to make

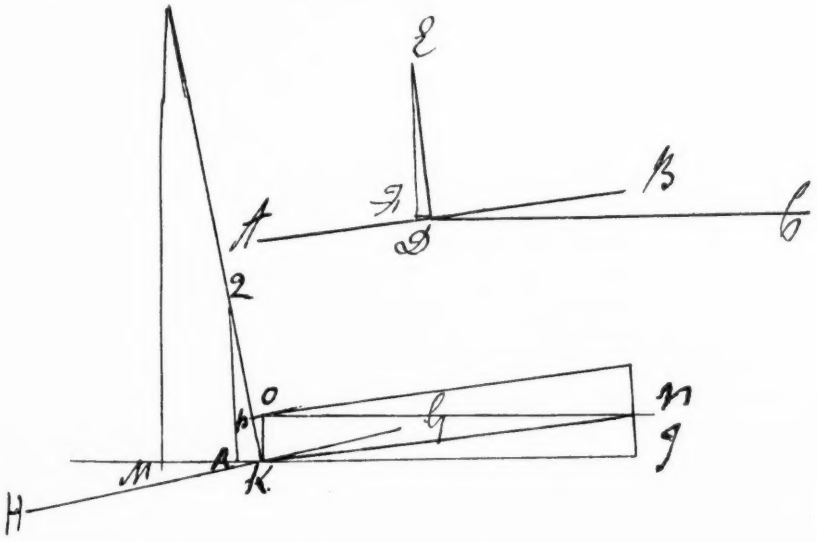


the same angle with the departing current as it did before with the approaching one. Let G H be the section of the wing, K I the current of the same velocity as before. It is evident that a new current I L equal in magnitude and position (with regard to the surface of the wing) with the former one C D must be created in order to support the bird. Consequently the wing must be moved either perpendicular to itself from L to K, or perpendicular to the horizon from L to M[2] (K M being parallel to G H) by which means I L is formed diagonally between the two motions. L N represents the whole pressure on the wing as in the former case, which being resolved gives N O = F E the supporting power, and L O the accelerating power = D F the retarding one. Therefore if these two positions of the wings be supposed to take place alternately in equal times the bird will be continually supported and will prolongue any velocity previously acquired, the retarding and propelling powers balancing each other and nothing more will be required in order to gain or extinguish motion than to increase or diminish the relative duration of these actions or their magnitudes.

[2] In the same time the current moves from I to K.—[G.C.]

In order to prove what has been said before that the velocity L M of the wing must bear the same proportion to the current I K that double the sine of the angle B D C, the wing opposed to the wind, bears to radius—the angle O L H is equal to $<$ B D C by construction,[3] as is also $<$ H L i : the angle O L I is therefore double to $<$ B D C—L O being parallel to I K, the $<$ O L I is equal to $<$ L I K, and L M, the velocity of the wing, is equal to the sine of this double angle, with the small additional part to complete the secant to the angle K L M, which is scarcely to be noticed in practice. However in exposing larger angles to the current this error in the rule would become considerable and must be taken into the account.

The two foregoing motions of the wing, however, form only 2 parts out of 3 that commonly occur in the flight of birds. I shall now endeavour to trace the laws of this third motion, which is that of elevating the wing from the lowest point of the beat to the highest point to prepare for a second beat. There appears at first view a kind of paradox involved in this action, as the wing recedes from the current of air and still the bird is supported. In very small birds who move their wings very rapidly compared with the progress they make, I believe gravity operates during the small interval unrestrained by any supporting power and the line of flight is undulated in jerks, but in large birds which strike but slowly, as the hern and the hawk, and consequently would fall several feet during the interval, an attentive observer may perceive that the wing supports them all the time, and indeed it cannot be otherwise as their line of flight seems perfectly straight.



Let A B be the wings, C D the current, E F the weight of the bird, and as before in the act of skimming. Now let the wing be turned to this current with double the $<$ B D C as represented by G H, and be in this position at the lowest point of the beat, the current I K being the same. Theory would estimate the increase of resistance at 4 times D E, or as the square of the sine of the angle of incidence, but experiment determines it to be in a mean between the

[3] The symbol for angle as used by Cayley has been retained.—[ED.]

direct ratio of the sines and that of their squares. I shall therefore put K L equal to three times D E, when L M will not be materially less than 3 times E F, and consequently the bird would in this case rise with a power doubly exceeding its weight—two-thirds then of this power can be spared and still leave sufficient to support the bird. Let K P be taken equal to the sine of the half the $<$ G K I and let P O be parallel to H G, then if the wing be moved perpendicular to itself from K to P or parallel to itself from K to O in the time the current moves from I to K, the diminution of resistance will be equal in both cases, P O representing that part of the motion K O which is in the plane of the wing, which leaves K P still for its diminution of impulse. Let O N be drawn parallel to I K and join I N. Then if K moves to O in the time that I moves to K, the diagonal N K will be in the direction and magnitude of the current, producing a pressure K Q equal or nearly so with D E, and a supporting power Q R nearly equal to E F: indeed in practice they may be esteemed perfectly equal, as the slightest conceivable alteration of angle would make them so, the whole error arising from the difference between the radius K I and its secant K N in an angle of 6°, and also between the difference of the sine E F of 94° and of Q R 88°. I shall therefore only observe that birds seldom or ever use their wings under so large an angle as I have here given, and that if the case of larger angles be required the differences thence arising are easily calculated from the above premises.

Aerodynamics

In estimating the mechanical power which a given plane will exert when exposed in any position to a current of fluid, two things are necessary, first the simple impulse of the plane must be obtained, and secondly the velocity with which this impulse can be supplied. The impulse is known to be as the density of the fluid, as the section of the current intercepted, as the square of the relative velocity of the current and the plane, and as the sine of the angle of incidence is to radius.[4] But this impulse acts in a line perpendicular to the plane and consequently if the power is to be applied in any other direction, the impulse must be reduced in the ratio of the cosine to radius of the angle formed between this perpendicular and the direction wanted. All these conditions are included in the following statement, tho' being more involved with each other they do not present themselves so immediately to the mind. The impulse is as the density of the fluid, as the magnitude of the surface, as the square of the relative velocity of the current and plane, as the square of the sine of the angle of incidence, and as the sine of the angle in which the power is to act. The velocity with which this impulse is supplied is that with which the plane must recede from the current (estimated in the direction of the current whether oblique or direct) in order to suffer no increase of impulse by allowing the current to overtake it too rapidly, or by being so fast as to diminish the impulse by diminishing the relative velocity of the current to it. Deduct the velocity of the absolute velocity of the wind and the difference is the velocity of the power—which multiplied by the impulse gives the power required.

Velocity of Bird-Flight

I measured the velocity of several crows in flying during a calm day, when the birds, not being disturbed, flew from place to place leisurely. The average result was that their usual speed is 34½ feet per second or 23 miles per hour. They could during any part of their course at this velocity stop beating and skim

[4] As pointed out by Mr. W. O. Manning, this is the first known reference to the fact that the lift of a plane varies as the square of the relative air speed multiplied by the density. *Cf.* Bryan, Prof. G. H., "Stability in Aviation," 1911.—[Ed.]

for many yards. Hence as their surface is in a proportion of a square foot to a pound, it follows that the pressure under their wings at this velocity must be in this proportion, and if it be supposed that the plane of the crow's wing opposes the horizontal current in an angle of 6°, it would very correctly agree with the French experiment on angular resistance, which allows a pound pressure on a foot surface in this angle moving at the rate of 33 2/10 feet in air.[5] The leisured flight of a tame pigeon is at the rate of 27 feet per second, or 18 miles per hour. I did not however ascertain this so correctly as the former instances which may be relied on. The quicker flight of the pigeon much exceeds 30 miles per hour.

Flight of Crows

On an average of 13 experiments taken with a stop watch, crows make 2.674 beats downward in one second. This I ascertained very accurately on a long average of 444 beats or wafts made by 13 different crows (rooks) in the course of 166 seconds, at 13 different times of observation in a calm day. As crows fly at the rate of 34.5 feet per second they make one beat every 12.9 feet, say 13 feet, and as we may probably allow a length of .75 feet or 9 in. for the extent of the beat estimated at the centre of resistance in the wing, it follows that 4 feet per second is the velocity of the stroke, on the supposition that the ascending or return of the wing is performed in the same time as the descending stroke. But it is more probable that the velocity of the descending waft exceeds that of the return in about the ratio of 5 to 3. In this case the velocity of the beat would be 5 feet and the return only 3 feet. Supposing the longest circle that can be described in the body of a crow to be 12 in. in area, a proportion not far from the truth, such a surface moving at the velocity of 34.5 feet gives a resistance equal to .216 of a pound, which reduced by the proportion given by Mr. Robins of the resistance of a sphere to its great circle (as 1 to 2.27), gives a resistance of .095 of a pound, had the breast been hemispherical, but being the curve made use of by nature for least resistance, I think we may safely deduct one-third of this quantity and take .0632 lb. as a quantity somewhat approximating the truth.[6]

[Note].—The whole motion of the wing both up and down can only amount to 4 feet per second.

Experiments in Aerodynamics with a Whirling-Arm

Dec. 1st, 1804. I made the following experiments upon the resistance of air to a surface of a foot sq, carried round with an horizontal motion upon an arm suspended upon a delicate hinge. The length of the arm from the pivot to the centre of resistance was 4 feet 9.2 inches. This arm played up and down upon an hinge fixed into the part that was carried round by the upright pivot, and counterpoised by a weight on the other side of the hinge, so that the 1/16 of an oz. turned it easily from an horizontal position. The whole was braced by a cord over an upright in a part of the frame to give firmness to the structure.

The motion was communicated by a cord going over a pulley and then down a stair case, with a bag to hold weights at pleasure.[7] The angles which the plane made with the horizon were measured by a plummet quadrant, and the weights lifted upon the path of the plane by a pair of common scales. The number of revolutions carefully noted with a stop watch.[8] The centre of resistance was computed by squaring the velocities that each vertical stripe of the

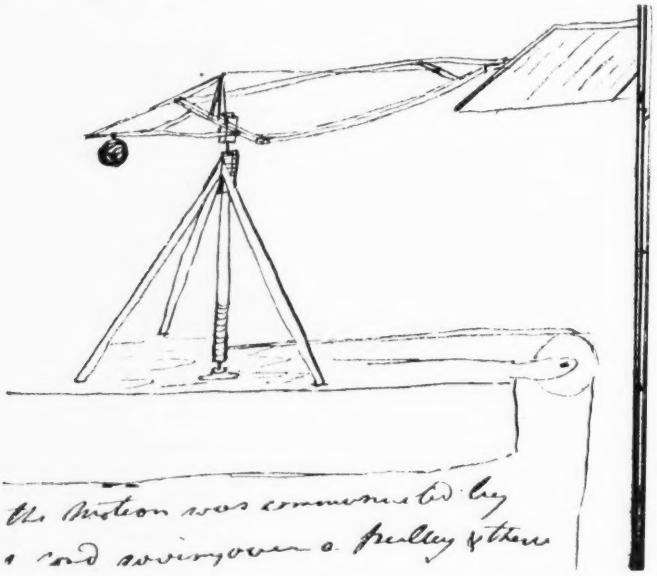
[5] On the authority of M. Charles Dollfus the experiments referred to "were conducted by D'Alembert, Condorcet, and Bossut in 1763," and published by the first-named.—[Ed.]

[6] Robins, B. Mathematical Tracts, ed. by J. Wilson, 2 vols., 1761, vol. I., p. 200. See also Introduction to this Note-Book.—[Ed.]

[7] See page 552.

[8] Robins used a stop-watch in his whirling-arm experiments of 1742.—[Ed.]

square one foot wide gave, and finding the medium point of resistance. I first selected a velocity of about 21 feet ½ (21.82 feet) per second, conceiving that this gave one pound pressure upon a foot surface when perpendicular to the



motion—as given me by Mr. Chapman.[9] Hence I weighted the machine so as to make 8 revolutions in 11 seconds. The weights supported under this velocity were as follows:—

Angle.		Vel. in ft.		Weight supported oz.
3°	...	21.8	...	1
6	...	do.	...	1.5
9	...	do.	...	2.5
12	...	do.	...	2.75
15	...	do.	...	4.125
18	...	do.	...	5.187

Afterwards I chose 8 revolutions and one eighth part in 16 seconds, supposing that in the proportion of the squares of the velocities I should have ½ a pound pressure per foot if perpendicular to the motion at this velocity, which gives 15 feet per second The results were as follows:—

Average.	Angle.	Vel. ft.	Weight sustained oz.		Ratio.	Ratio.
1.	3°	15	.562	=	1.	1
1.35	6	do.	.687	=	1.21	1.5
2.59	9	do.	1.25	=	2.68	2.5
3.10	12	do.	1.938	=	3.45	2.75
4.43	15	do.	2.687	=	4.75	4.125
5.18	18	do.	2.887	=	5.18	5.187

[9] Doubtless W. Chapman (1749-1832), of Newcastle, but the actual reference cannot be traced. Cayley corresponded with Chapman on an oil-of-tar engine—see Cayley's article on Aerial Navigation, Nicholson's Journal, Vol. 24, 1809, p. 164.—[ED.]

By a mistake an angle of 20 was tried in lieu of 18 with a velocity of 21.8 feet. It sustained 5.375 oz.[10]

The enormous power required prevented me from extending the range of angles. Indeed the larger angles are far better known already and agree with the theoretic laws of resistance much better than the lesser ones. Upon this apparatus I however tried the direct resistance of the square foot, and found that a velocity of 17.16 feet per second gives a pressure of ½ a pound exactly. I first ascertained that a force of one ounce gave the arm this velocity when the plane was removed. I then weighted the machine so as to press with a force on the centre of resistance 9 oz., but considering that one ounce would scarce give the required velocity to the arm, under the additional friction the weight necessary occasioned (which was more than 30 pounds), I added half an oz. more, and then I conceived that the pressure that would be received by the plane would be very correctly half a pound. I measured the horizontal tendency of the arm to move when thus loaded by carrying a string under a pulley and then connecting it to a pair of scales. I likewise examined it by a delicate spring steelyard, and it was precisely by both measures 9½ oz. I allowed the whole to take 2 full revolutions to gain its proper velocity, and after that it performed 20 revolutions in 35 seconds precisely, hence it moved 600 feet in this time equal to 17.16 feet per second. If then the resistance increases exactly as the square of the velocity, 24.3 feet will generate a pressure of one pound on a square foot, or to be more exact 24.287 feet. In another instance I weighted the machine with 17 pounds, which just balanced 4¾ ounces, the ¼ of an ounce being required to make the arm turn at a velocity 12.1 feet per second, or 10 revolutions in 25″. The plane under this pressure made 20 revolutions (600 feet) in 52 seconds, equal 11.538 feet per second. This would give (according to the square of the velocity) 23.1 feet velocity to produce one pound pressure on a foot surface. Now in this case if the ¼ of an ounce allowed for friction be supposed to operate with its full effect on the plane, then a velocity of 11.53 feet received a pressure of .25 lb. + .0156 = .2656, and even this would give 22.3 feet of velocity to generate a pound pressure. Therefore I have no doubt that about 23.5 or 24 is the standard velocity. The experiments were done with great care and often repeated with the same results, and made on such a large apparatus and upon so long an average that they must be tolerably correct. I had not a barometer to note the weight of the atmosphere at the time.

1815.

N.B.—On measuring the frame I find it wanted 1/7 of an inch of a foot on one side, though an exact foot on the other. Hence it was 1/84 part less than a sqr. foot.

N.B.—The surface was paper perfectly tight over a frame.

I have my doubts however whether this mode of circular motion does create as much resistance as when the plane moves on in a right line keeping parallel to itself. A common paper kite containing 154 sqr. inches was fastened to a rod of wood at the hinder end and supported from the fore part from the same rod by a peg, so as to make an angle of 6°. With it this rod proceeded on behind the kite and supported a tail, made of two planes crossing each other at right angles, containing 20 inches each. This tail could be set to any angle with the stick. The ratio about 5 sqr. feet of surface to the pound—velocity 10 miles per hour.[11]

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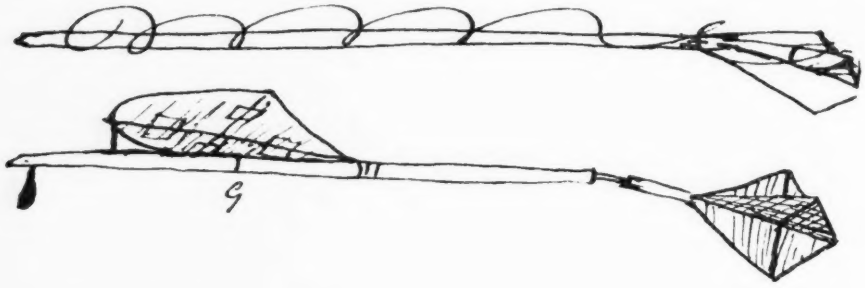
[10] The earliest known experiments in aerodynamics made with a whirling-arm for the purpose of obtaining data applicable to mechanical flight, and the first in which different angles of incidence were tried.—[Ed.]

[11] The following sketch of "Cayley's first model aeroplane, 1804," has been incorporated in the design of the new British Gold Medal for Aeronautics.—[Ed.]



The centre of gravity was varied by sticking a weight with a sharp point into the stick. The whole weight was 3.82 oz., and when the centre of gravity, G, was under such part of the kite as left 75 inches on the anterior part and 79 behind it, and with the tail at an angle of 11.5° (the centre of resistance of which was 27½ from the centre of gravity), then if a velocity of 15 feet per second was given to it in an horizontal direction, it would skim for 20 or 30 yards supporting its weight, and if pointed downward in an angle of about 18°, it would proceed uniformly in a right line for ever with a velocity of 15 feet per second. It was very pretty to see it sail down a steep hill, and it gave the idea that a larger instrument would be a better and safer conveyance down the Alps than even the surefooted mule, let him meditate his track ever so intensely. The least inclination of the tail towards the right or left made it shape its course like a ship by the rudder.[12] Now the kite being 154 inches and the tail 20—which being at such an angle as gave (according to the former tables) a pressure double to that of the kite—the whole may be supposed equal to 194 inches supporting 3.82 oz., equal to a square foot supporting 2.85 oz. at this velocity, and therefore at a velocity of 21 feet per second it would support 5.6 oz., whereas by the tables of circular velocities just related there appeared only a support of 1.5 oz. Also crows have a foot surface and move 34.5 feet per second supporting a pound, and the angle is not perhaps more than 3° or 4°. However their wing is concave, which resists much more than a plane surface and the paper on the kite might not be tight. In the kite—according to the square of the velocity—one foot at this angle would support a pound at a velocity of 34.5 feet. A crow has a surface exactly in this proportion, and its velocity is 34.5 feet per second—hence the angle of the crow's wing cannot exceed 6°.[13]

Aerial Navigation

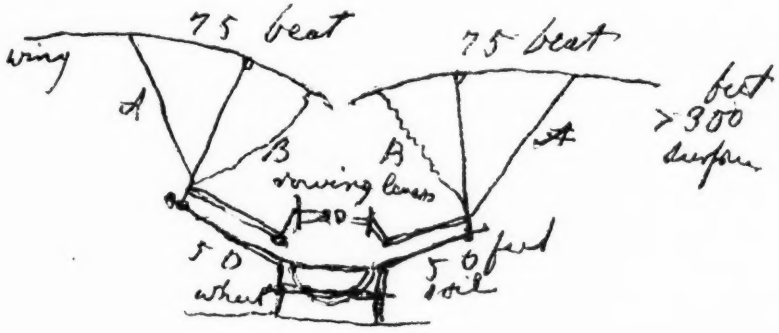
In aerial navigation by mechanical means the magnitude of the surface is a considerable impediment from the necessary weight of its construction. Feathers in birds seem a most admirable structure for the purpose in their construction, but even these are a considerable weight. I kept the whole of the bones and wings of a tame goose from the first joint, and when they were perfectly dry they weighed 7 1/6 oz. Their surface was 306 in., hence one foot surface weighs 5.5 oz. Suppose the surface for a man to be 300 feet, it might weigh 150 lb. and more to keep this proportion of weight, but 300 feet of cloth strong enough for the purpose would not weigh 10 pounds, and if the poles,

[12] The earliest recorded experiment with an aeroplane or gliding machine, having both vertical and horizontal rudders, in free flight. The date is 1804.—[Ed.]

[13] Mr. Nayler points out that Cayley knew nothing about "aspect ratio." But *cf.* p. 555 post. The importance of this factor was first fully realised by F. H. Wenham in his paper on "Aerial Locomotion," 1866. (Aeronautical Society of Great Britain, First Report, 1866.)—[Ed.]

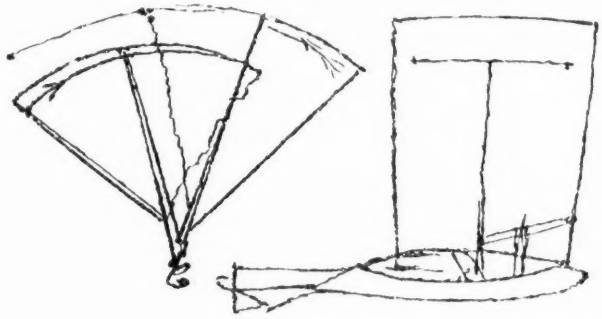
&c, &c, on which it is stretched amount to 30 lb., the whole would only be 50 lb., and be 3 itmes lighter in proportion than the surface of the goose's wing.

Sketch of Winged Flying Machine



A, tight in beat, B, tight in the return. The extreme ends of the wings propel both in the beat and return and they support both ways.[14] G. C.

Sketches of a Flying Machine

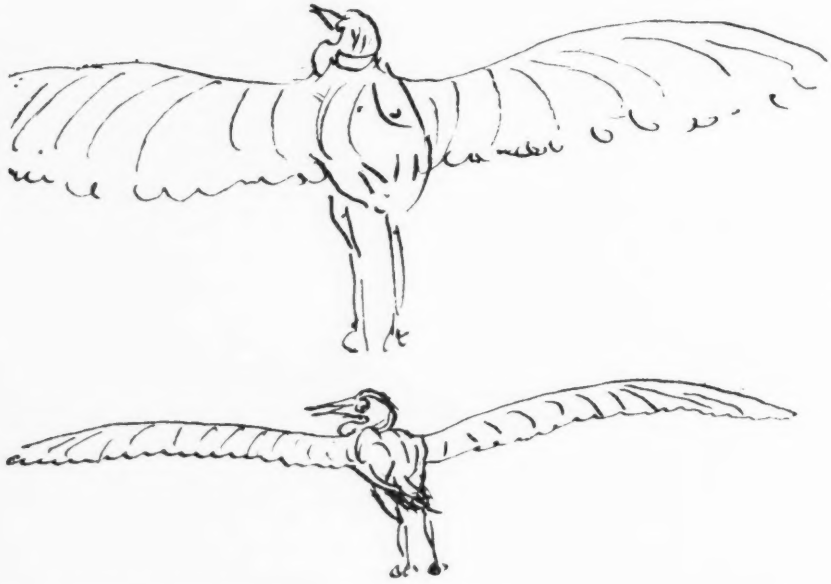


Surfaces in the inverse ratio of the square of their velocity or distance from the centre C.

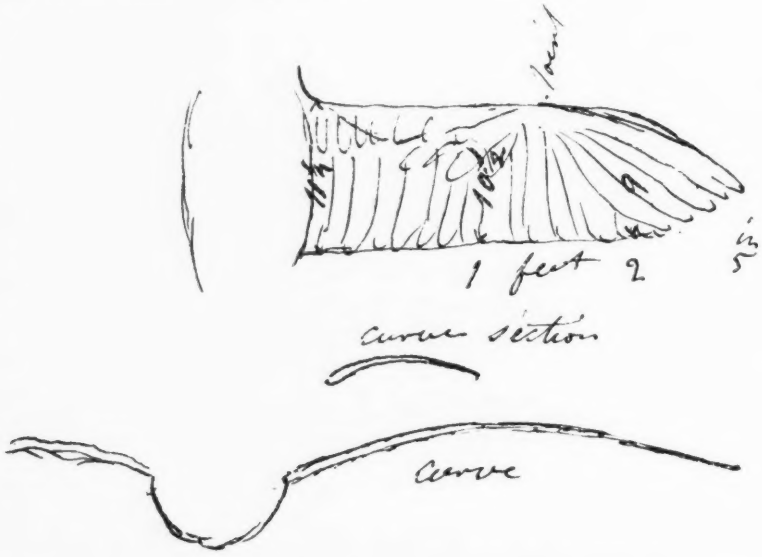
Wing Surface of Herons

Feb. 19th, 1808. I shot a common heron, it weighed 3 pounds within a quarter of an ounce, and the surface of each wing was 2 feet exactly. Hence 3 lb. has 4 feet surface to support it. This is in the ratio of 1.32 feet to a pound. This bird seems peculiarly light upon wing and wafts very slowly. Its wings are very concave and are not in one plane, but in an arch (see p. 556). I observe this arch likewise in the sea-gull, which is also a light bird. I am apt to think that the more concave the wing to a certain extent the more it gives support, and that for slow flights a long thin wing is necessary, whereas for short quick flights a short broad wing is better adapted, with a constant flutter

[14] Evidently added at a later date than 1805.—[Ed.]



as the partridge and pheasant. But the convenience of the circumstances of the bird regulates the kind of wing that can be commodiously given them. The shape of the heron is as follows:—



The extreme ease with which this bird seems to support itself, tho' not of so light a ratio as the gull and some other birds, would lead one to think that the

resistance increases quicker than the ratio of the surface merely. Indeed it has been observed to be so by experiment, tho' not much. The wings when cut off weighed 9 ounces. Hence one pound makes a surface of 7.1 feet and 300 feet would at this ratio weigh 42 lb.

Ornithopter Flying Machines

Memorandum. The utmost speed I can run with over a short space of 30 or 40 yards when having acquired my full velocity, is at the rate of 20 feet per second, or 13.6 miles per hour. Hence with a surface in the ratio of 1.5 feet per pound at the effective angle of the crow's wing, whatever that may be, only .48 of his weight would be suspended by the plane, but by doubling the angle he would be totally elevated.

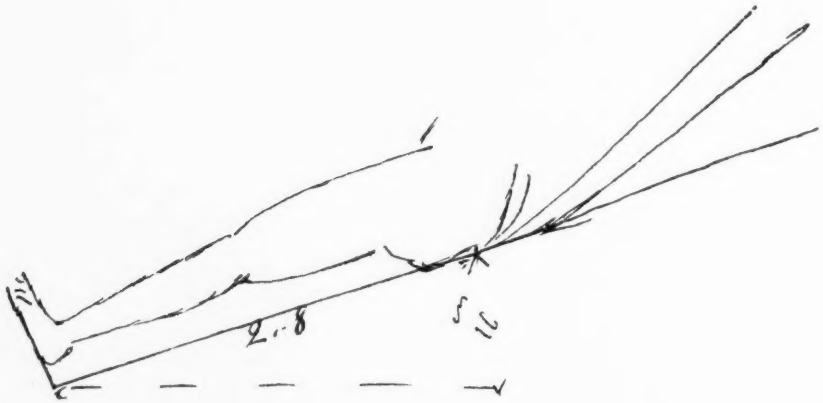
To avoid the inconvenient weight of a car and wheels, etc., I have thought that if two substantial loops, well padded, came from the middle pole, so that a man could put his arms over them and hold by his hands to a lower projecting piece from these loops, that then he might run the machine till it bore him up, when placing both his feet on a broad canvas belt (which would kick off from him in running), he could then work the wings and counterpoise with the full strength of his person most advantageously applied. There would be no friction and the whole need not exceed 30 lb. in weight, or 40 at most.

Vide sketch—Brompton, March 11th, 1808, G.C.

I find that the proper distance from the foot to the centre of the seat, so as to admit me to work with the greatest advantage, is 2 ft. 8 in., and that the elevation of the seat above the heel need not exceed 10 in.

The seat being with this slight elevation was more agreeable than when horizontal.

On the other side I have sketched a very light construction of a seat upon the principle of the man running the machine up, and then seating himself and working the wings by two cords over pulleys and rings to place the hands in. If this can be done it obviates all necessity of a car and wheels which are only suited to the power of some first mover. With 300 feet surface and the weight in all 200 lb., a velocity of 28 feet per second would raise it at the usual angle of the crow's wing in the act of skimming. Hence at 20 feet (the utmost of my running) at this angle exactly half my weight would be supported, and by increasing the angle something short of double it would lift the whole up pro-



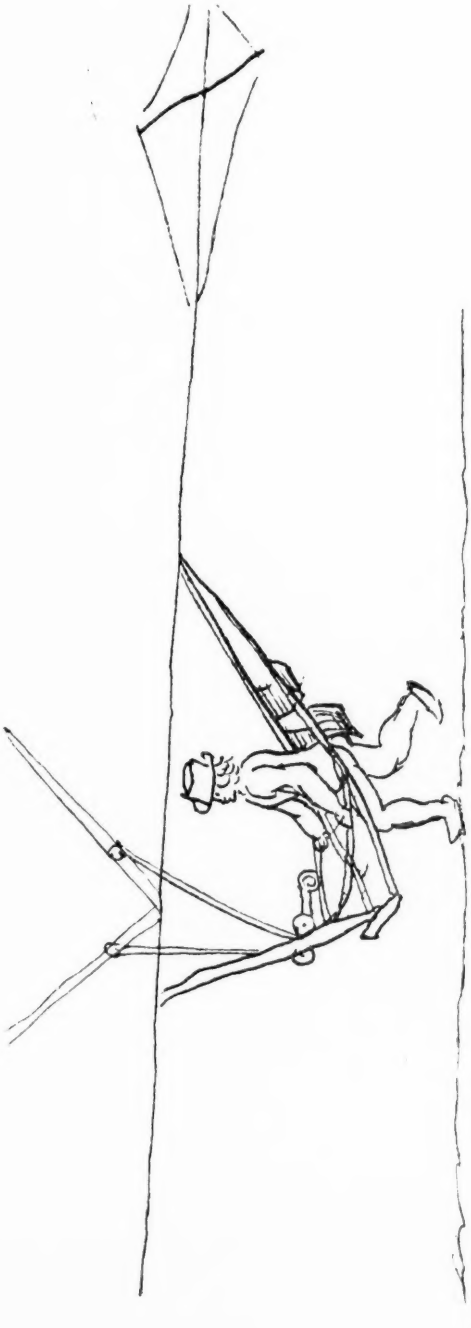
bably at an angle of 6°, for I believe the usual angle of the wing is not more than 3°. A fall of 6.3 feet gives any body the velocity of 20 feet per second, hence on an inclined plane at 6° a ball at this velocity would roll up till it rose 6.3 feet, and must therefore proceed about 60 feet in so doing. Now the plane being in this angle is resisted at first no more than such a ball, and its motion would not be extinguished till it had arrived in an horizontal path 60 feet, with an uniformly retarded velocity proportional to the ball advancing obliquely against gravity, provided the medium increased in density just in the ratio that the velocity decreased. But as the density of the air continues alike, a very complicated variation of angle must be made, so that the resistance which varies nearly as the sine of the angle of incidence shall keep place with the decrease of velocity, and also have regard to the want of perpendicular support of the plane by its materially increased obliquity. Probably this would reduce it to rest rather short of half the way, or at about 27 feet, occupying about 2 seconds, in which time the man I think might seat himself and use the propelling power of the wings, particularly with the advantage of a slight declivity (see page 559).

If birds have an advantage in the small extension of surface necessary for their support, we have the advantage of making much less comparative resistance in passing thro' the air. An instance will best shew this. A crow weighs a pound, and the largest circle that can be described in his body contains 12 square inches. Hence if a man weighed only 60 lb. his surface which is about 5 feet would only be proportionate to the crow. But he weighs 150 lb., therefore his resistance even erect is $2\frac{1}{2}$ to one in favour of the man, but being cylindrical in lieu of real solid of least resistance, may reduce the proportion, but still in all probability he will not resist more than half in proportion with the crow, if no proper shape car be placed before him.[15]

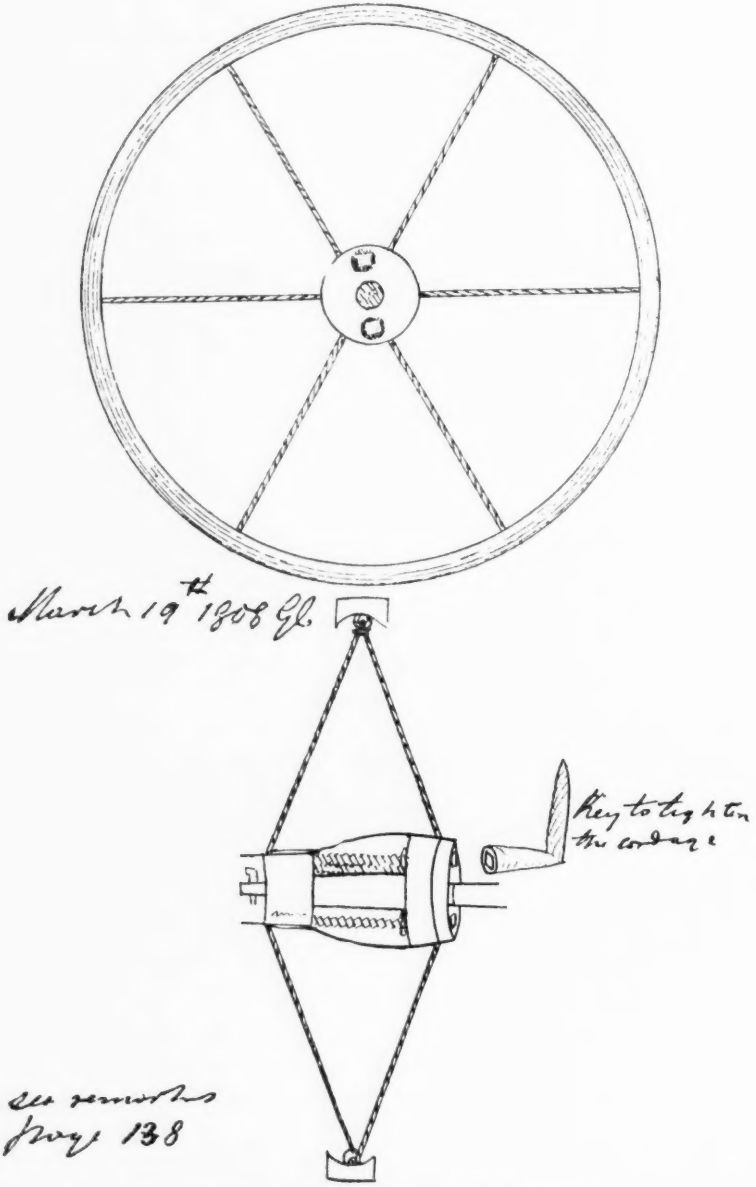
Tension or Suspension Wheel for Aerial Navigation Cars, 1808

In thinking how to construct the lightest possible wheel for aerial navigation cars, an entirely new mode of manufacturing this most useful part of all locomotive machines has occurred to me—vide, to do away wooden spokes altogether, and refer the whole firmness of the wheel to the strength of the rim only, by the intervention of tight strong cording, as exhibited in the front and side

[15] Mr. J. L. Nayler comments: "Cayley has forgotten the question of h.p. to be expended. A man could just fly under his own power for a few seconds only." *Cf.* Lilienthal, O., "Birdflight," 1911, p. 10, etc.—[Ed.]

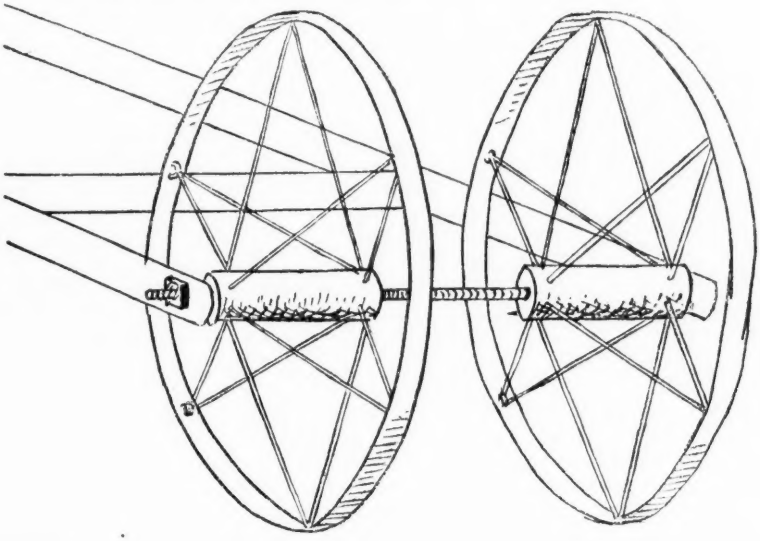


[UNDER-FRAME OF ORNITHOPTER FLYING MACHINE]



[TENSION OR SUSPENSION WHEEL]

elevations on the opposite page. Such a wheel would I am confident be almost everlasting for light travelling vehicles, would be very beautiful, give no shake and therefore require much slenderer axle trees, and have less friction. If the rim were of thin cast iron and likewise the nave, with some proper screw apparatus to stretch the cordage, nothing would ever require renewing but the cord, and this seldom, as it would never receive any jar like a wooden wheel. No noise would be given to the loose parts of the vehicle and with good springs travelling would be much pleasanter. The cordage must be well soaked in tar or other resin and thickly painted to prevent the action of water upon it. Probably the simplest way of tightening the cordage at pleasure would be to have the hinder part of the nave separate from the front, to wedge each end in tight when the blocks are together, and then by four screws to stretch them open till the proper centre of nave be obtained, leaving room for more if after wear it be required. The two blocks must slide upon a hollowbox including the axletree. Still further to reduce the friction of wheels, I think that it would be a very great improvement to use the strength of the iron employed as an axletree in the best possible way, and by so doing reduce the dimensions at the working part very much indeed. At present the strength of the axletree depends upon the capacity to resist bending or breaking by the force of a lever of the radius of the wheel. I propose to remove this mode of the application of its strength altogether, and like the cord spokes, apply the enormous power of the cohesion lengthwise of the bar. To do this it is only necessary to have 2 strong supporters on the outside of the wheels and then string the wheels on a wire of any required strength between, as sketched below.

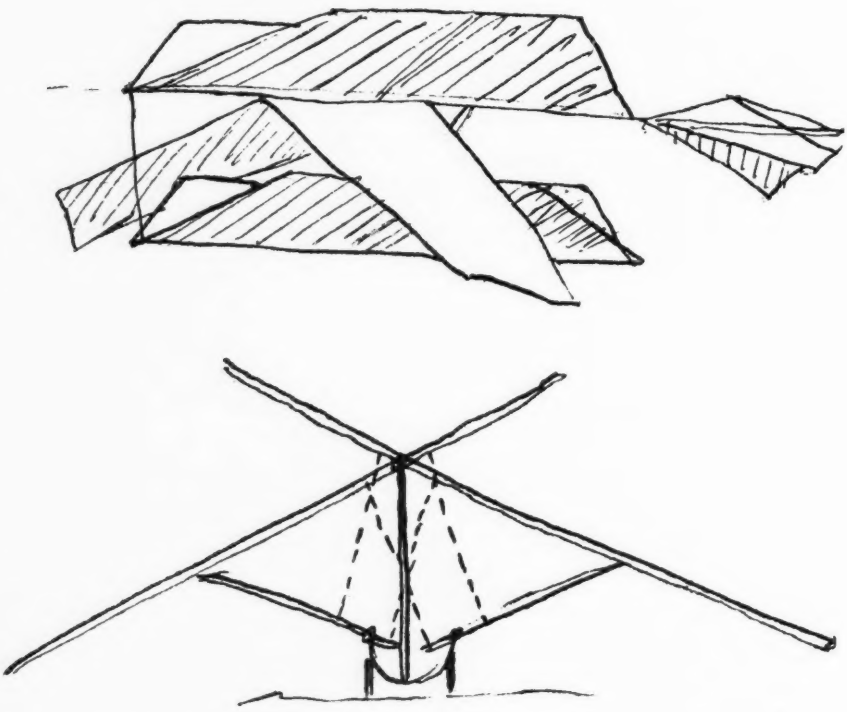


Hence if the outside supporters be firm any twist of the wheel only tends to pull the slender axletree in two length-wise. A wire of iron ½ inch in diameter will bear in this direction fifteen thousand [one] hundred pounds, or 6 and a half tons.[16]

[16] The following paragraph must have been added many years later. Theodore Jones's patent for improvements on wheels of carriages (No. 5415) was taken out in 1826.—[Ed.]

These wheels since patented by Jones just as Mr. Donkin and I were engaged in preparing to do so. I suspect the secret crept out.

Ornithopter Flying Machine

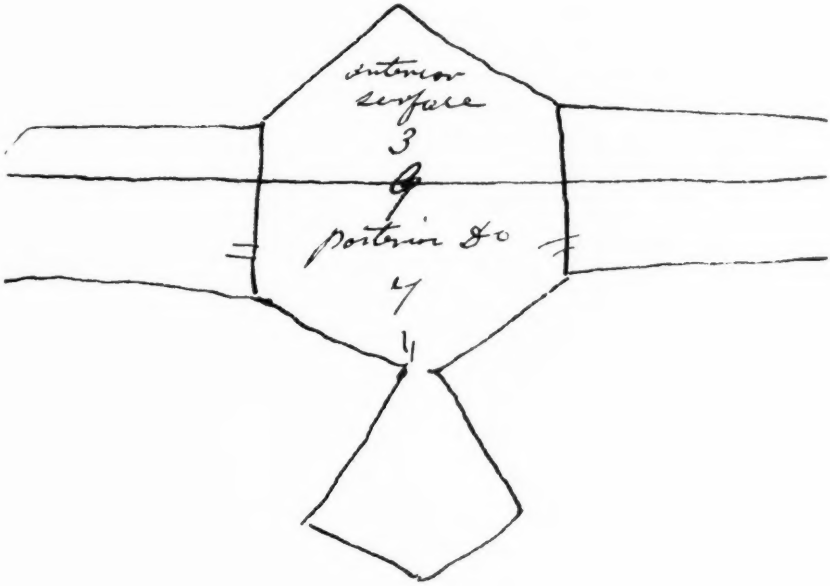


To reduce the length of the poles and render the bulk of the machine less, above is a mode of giving each wing 2 counterpoises by blending 2 former plans.

Experiments with Kites

Apl. 3, 1808. By an experiment made with a large kite formed of an hexagon with wings extended from it, all so constructed as to present a hollow curve to the current, I found that when loaded nearly 1 lb. to a foot and $\frac{1}{2}$, it required the centre of gravity to be suspended so as to leave the anterior and posterior portions of the surface in the ratio of 3 to 7. But as this included the tail operating with a double leverage behind, I think such hollow surfaces relieve about an equal pressure on each part, when they are divided in the ratio of 5 to 12, 5 being the anterior portion. It is really surprising to find so great a difference, and it obliges the centre of gravity of flying machines to be much forwarder of the centre of bulk than could be supposed a priori.

It should be observed that these wings were considerably hollow and much wood that made direct resistance, and that they were not in one plane but



inclined upwards. Hence the centre of support was much above the centre of gravity, and as the weight was the moving cause, being projected horizontally the retarding power of the plane arising from its degree of obliquity to the horizontal path, and also the direct resistance of the wood work, operated to depress the hinder part of the balance. This will most probably account for the necessity of the centre of gravity being obliged to be removed forward. I tried a small square sail in one plane, with the weight nearly in the same, and I could not perceive that the centre of resistance differed from the centre of bulk.[17]

Sketch of a simple construction of a wing and counterpoise. A of A, B of B. (Pages 564, 565.) Apl. 2, 1808.

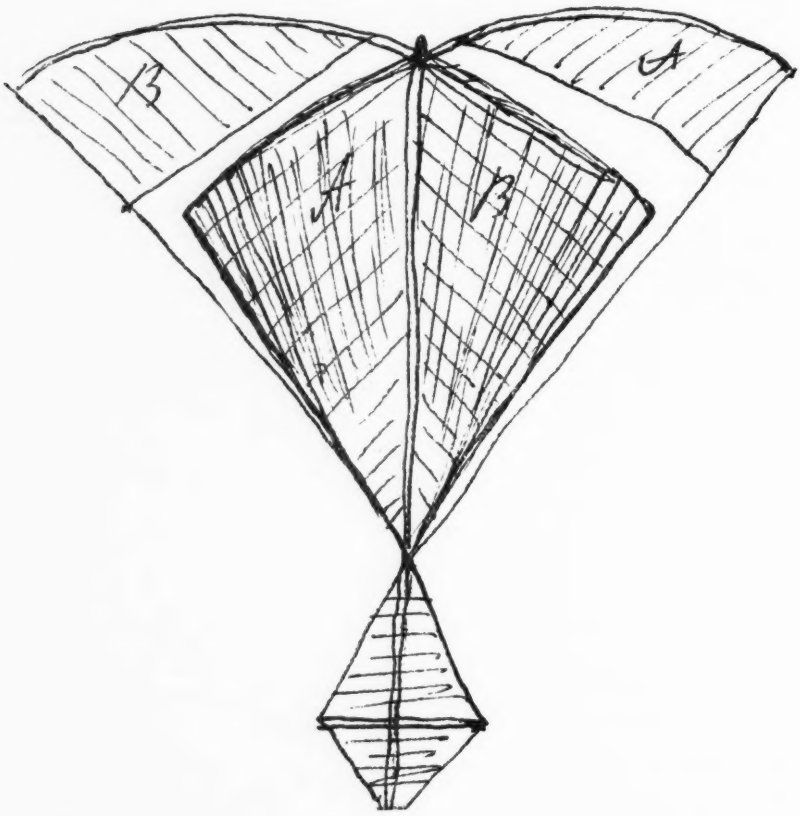
Ornithopter Flying Machine

May 12th, 1808. Sketch of the lightest and strongest form of a middle pole and seat for aërial navigation, the pole to be made in halves, tapering each way from the cross-pieces and hollowed to form a tube. Bamboo canes would be most excellent rods for aerial navigation purposes. I almost think they had this purpose contemplated in their formation.

Solid of Least Resistance

Trout on a scale of half an inch to one inch. Weight (being a well fed fish) 13 ounces, length from nose to end of the centre of the tail, 13 inches. In the figure below, the girths are divided by three and reduced to a mean diameter,

[17] These experiments are the earliest known attempts to investigate the problem of the "centre of pressure."—[Ed.]

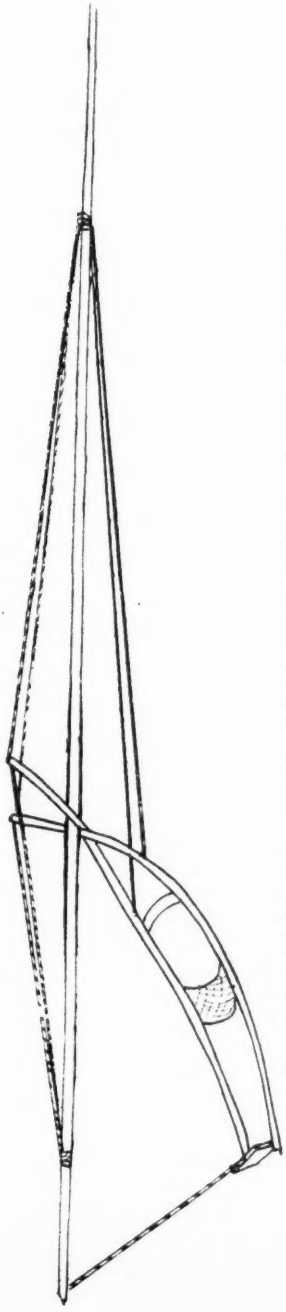


so as to give a spindle the same girth at the respective places that the trout had. Why should not a boat be constructed to resemble one half of such a spindle by a section thro' the axis? We should then be deriving our boat from a better architect than man, and should probably have the real solid of least resistance.[18] June 20, 1809. (See page 560.)

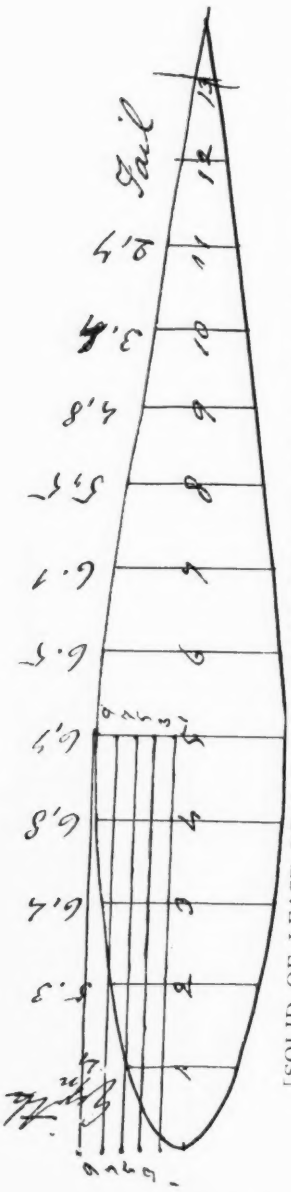
Wings and Muscles of a Crow

Dec. 15, 1809. I shot a Royston crow. It weighed 1 lb. 5½ oz. Each wing had a surface of 96 sqr. inches. According to this ratio a pound would have 140 inches to support it. This is very nearly the same as the rook. The largest circle in its breast is only 9 sqr. inches; the usual surface of its tail is 20 inches, the feathers being 21 in number and six inches long, but when formed in the act of stopping flight it measures 45 or 50 sqr. inches. The whole length of the bird is 19 inches. From bill end to the eye 2, from the bill end

[18] The real solid of least resistance is still an unsolved problem. Doubtless the problem interested Cayley in connection with "navigable balloons." *Cf.* the aerofoils of airships in the Handbook of Aeronautics, 1931, p. 243.—[Ed.]



[UNDER-FRAME AND SEAT OF ORNITHOPTER FLYING MACHINE]



[SOLID OF LEAST RESISTANCE BASED ON THE MEASUREMENTS OF A TROUT]

to the commencement of the wing membrane 6, to the root of tail feathers 12, to the end of the body feathers forming the taper of the spindle 16, girth round the head at the eye 5·75 inches, girth round body at setting on of the wing 10.75 in., balancing point 8½ from bill nib. When the wing is spread as in flying the feathers only are contiguous for 12 inches, the five quill feathers then become suddenly lessened in their width and stand like fingers, leaving spaces between each. I believe this is common to the crow tribe and is probably for the purpose of gaining the propelling power both in the up and down waft, these breaks allowing of a greater obliquity in each feather than could conveniently be if all were united in one surface. The wings weighed 2¼ oz., hence 1 lb. would construct a surface of 9.6 feet.

Also a view of the tendon of the inner pectoral muscle, which having passed thro' a grooved hole formed between the clavicle and scapula, terminates just opposite to the commencement of insertion of the pectoral muscle.[19] This tendon operates as an additional ligament in giving strength to the joint from the twist which the air under it endeavours to give in consequence of the leverage of each feather. Both the fixed ligaments are so placed as only to oppose this effort, and the only stay to the joint turning the other way is its muscular connexions. The large pectoral muscle when carefully dissected off weighed 3¼ ounces, being 1-6th of the weight of the bird. This muscle alone produced the waft of the wing, and being inserted forward of the centre of the joint, tends to heel up the wing backward to gain the propelling power. On the contrary the internal pectoral muscle, which with some others elevate the wing, tend at

[19] See page 568.—[ED.]

the same time to heel the hinder edge down, which answers the purpose of giving support by increasing the angle with the current, and may add to the propelling power in the same act.

Inside Joint
& Ligament.
Back View of a bracing
Ligament commencing on the
Scapula & passing over a projecting
process with a groove to receive it
into deep cavity in the head of the humerus.

CORRESPONDENCE

To the Editor of the ROYAL AERONAUTICAL JOURNAL.

Dear Sir,—Respecting the paper on physiological limits of altitude or height in the current issue of the Journal, I do not know whether the following remarks would be of sufficient interest to publish in your next issue.

So far as I could gather from reading the paper and discussion there was no mention of the *ultimate altitude limit* at which the blood of the pilot would boil. This is in the region of approximately 50 millimetres mercury gauge pressure, and I believe I am right in saying this corresponds over a height approximately 60,000ft., that is to say, in a machine with an open cockpit.

On the question of oxygen supplied, I do not think enough attention has been given to the possibilities of subcutaneous injections of oxygen. I believe it is the practice of veterinary surgeons in cases of valuable dogs and other animals affected with pneumonia to inject oxygen under the skin and so supply oxygen to the blood independently of the lungs. This sounds somewhat drastic, but I believe that if practised in the case of high altitude mountain climbing, such as the ascent of the last stages of Everest, it might make all the difference. Calculation shows that a very small quantity of oxygen absorbed in this way would compensate for the last two or three thousand feet and last long enough to see the climber through, likewise it might be of use in extreme cases of high altitude flying, but the altitude limit in an open (no pressure) cockpit would still be 60,000ft. when even if the oxygen supply were maintained the pilot's blood would boil and he would burst. Moreover, at these high altitudes a subcutaneous oxygen supplied would have to be administered with great caution because the volume would be greatly augmented by water vapour.

On the question of caisson sickness, as this is due to nitrogen bubbles being disengaged in the nervous system ("Caisson Sickness," by Leonard Hill, F.R.S., chaps. V and VI), there is very little to fear on this account when pure oxygen is being breathed; but otherwise it would be rash to say that caisson sickness might not arise from rapid decompression, because it is not entirely a matter of absolute decompression in lbs. per sq. inch, but to some extent it is due to *relative* decompression.

Yours faithfully,
F. W. LANCHESTER.

May 10th, 1933.

To the Editor of the ROYAL AERONAUTICAL JOURNAL.

Sir,—In reply to Dr. Lanchester, it is perfectly true that since the vapour-pressure of pure water at body temperature is just under 47 millimetres of mercury, any water in the body, containing no salts in solution, would boil at a height of about 62,000 feet (I.C.A.N. height-pressure law). I did not mention this in my paper (though I made passing reference to it when speaking before your Society) because I had already postulated a lower physiological limit of height, of the order of 45,000 feet, from the factors governing the assimilation of oxygen by the blood, so that a pilot who was carried to a height of about 62,000 feet would have succumbed long before.

With regard to the subcutaneous injection of oxygen there are three things to be taken into account. The skin of dogs is much more loosely attached to the underlying tissues than that of man and can be gathered together by the handful without injury, so that relatively large quantities of gas could be injected under it; while the amount of oxygen that would be necessary to supplement the breathing of pure oxygen at atmospheric pressure at any attainable height largely in excess of 45,000 feet would, if given subcutaneously, produce a painful and extremely incommoding condition of ballooning of the skin, which would make the necessary movements of piloting almost impracticable. Even if these objections could be overcome, the risk of septic infection through the numerous punctures, and the difficulty and discomfort involved make this too much of a surgical operation to be contemplated in connection with a pilot actively engaged in manipulating controls while swathed in several thicknesses of clothing. These objections acquire added force if one compares the extreme physical exercise involved in climbing Everest with the almost complete placidity, and therefore minimal oxygen requirement, of a sick dog.

Turning to Dr. Lanchester's reference to caisson disease, in view of the facts mentioned in my paper that the total range of decompression that it is possible to encounter in aviation can never reach one atmosphere, and that no practicable rate of ascent is even comparable with the rate of ten thousand feet *per second* that has been attained experimentally without apparent detriment, I am still of the opinion, in which Sir Leonard Hill concurs (*vide* p. 402 of your Journal), that there is no danger of caisson disease in flying.

I am, Sir, your obedient servant,

G. S. MARSHALL, *Wing Commander.*

Central Medical Establishment,
Royal Air Force,
3-4, Clement's Inn, W.C.2,
24th May, 1933.

REVIEWS

Aero Engines, An Elementary Treatise

Vol. I. John D. Frier, F.R.Ae.S. C. Griffin and Co. Price 10s.

This useful text book is the latest addition to Griffin's Aeronautical Series, and is the result of a praiseworthy attempt on the part of the publishers to produce a series of text books suitable for students and others at a lower price than that at which they could formerly be obtained.

This book by Mr. Frier is an excellent example of what can be done in this way. He has dealt with the various sections of his subject clearly and adequately, and there are ample references to more voluminous works so that the student who desires further information on some particular aspect of the subject will know where to look.

Naturally nothing in the way of novel treatment is to be expected or desired in a book of this nature and Mr. Frier has wisely followed conventional lines; but there is one matter which should be explained, and that is the character of the load imposed on the engine by the propeller. It is clear that aero engine design cannot be adequately comprehended unless propeller peculiarities are understood.

It is possible, however, that Mr. Frier intends to rectify this omission in his next volume, but however this may be, this book is one that can be thoroughly recommended as an excellent text book of its class.

The Technical Report of the Aeronautical Research Committee

1931-2. Price £1 15s. 0d. H.M.S.O.

This report indicates that steady progress is being made in the solution of the many problems concerning flight, and in one or two of the more important ones it would seem that a certain degree of finality is in sight. This would seem to be the case in the problem concerning the spinning of aircraft where the masking of certain controls by others has been shown to be of fundamental importance in recovering from a spin; and in the case of one aeroplane a rearrangement of the controls so as to modify this masking has been shown to correct the previous reluctance of the machine to come out of a spin.

It is possible, that in the case of military aircraft, where extreme manœuvrability is essential, spinning may have to be accepted as being correlated, but in the case of commercial aircraft the production of a spin-proof machine would be a most important development and one which should be attainable.

It is interesting to note the attention which is paid to matters of safety in this report, and apart from spinning, the buffeting of tailplanes receives further attention, and also the question of control at the stall. Much work has recently been done abroad on various novel methods of increasing the lift coefficients and improving the control characteristics of wings and we should not be left to obtain all our information on the effect of these devices from the work of foreign bodies.

Flutter receives further attention and must continue to do so until sufficient information is available to enable this trouble to be eradicated, and it is curious to note that attention is now being paid to the effect of lack of wing rigidity on

aileron control, a phenomenon which was noticed on certain machines over ten years ago.

Silencing of engines seems at last to be receiving adequate attention. Considering that a crude but effective form of silencer was used on the BE2 aeroplane in pre-war days, it is strange that so little progress has been made. It is to be hoped that in the near future all commercial aircraft will be fitted with silencers, to the greater comfort of their occupants and to the reduction of the annoyance of the general public.

Research is continuing on many engine problems, especially that of compression engines and that of lubricating oil. In the case of the former it is interesting to learn that the two-stroke C.I. engine is receiving special attention, as there are many reasons for believing that this type is the most suitable for aircraft use. Oil research seems largely to be concerned with stability, but the recent experiences with oil "dopes," such as lead of soap, should receive attention. Further information is wanted on the connection between the lubricating properties of a liquid and its molecular constitution, it is not necessary to assume that lubricating properties belong solely to the family of hydrocarbons.

With regard to materials of construction, progress seems to have been steady with the possible exception of beryllium to which no reference is made. It is presumed that the preliminary difficulties in preparing this material have not yet been overcome. It is, however, understood that alloys of this metal with copper can be obtained commercially in Germany.

Generally speaking, this report is well up to the excellent lead of its predecessors, and it is pleasing to note the steady and systematic way in which the solution of the many unsolved problems of flight is being attempted.

The 555th Lecture read before the Royal Aeronautical Society since its foundation January 12th, 1866.

PROCEEDINGS

Sixth Meeting, First Half, 68th Session

The Sixth Meeting of the first half of the 68th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, John Street, Adelphi, London, W.C.2, on Thursday, December 1st, 1932, when a paper on "The Behaviour of Fluids in Turbulent Motion," by Mr. A. Fage, A.R.C.Sc., F.R.Ae.S., was read and discussed. In the chair, Professor L. Bairstow, Vice-President.

The Chairman: The paper would deal with one of the more scientific aspects of aeronautics, an aspect which perhaps would not have wide practical applications for ten, twenty or, maybe, more years. Nevertheless, it was one of those subjects which appealed to the scientific mind as being of the greatest importance, in that it tried to take them as far as it could into the mechanism governing fluid motion. They were feeling more and more, as time passed, the need for seeing what happened in fluids. In the old days the problems which confronted those concerned with aeronautics were the problems of getting into the air at all, but to-day nobody doubts that aircraft can be produced which will fly, and at stated speeds. The simpler problems, therefore, had been solved so far that they had become everyday working problems; the problems arising to-day were more and more complicated, and in solving them they needed more and more insight into the way air moved. About twelve months ago a paper had been presented by Mr. Farren on "Airflow," which had illustrated very clearly and forcibly the use of smoke. But the kind of motion which Mr. Farren had been examining was comparatively coarse and open as compared with that which Mr. Fage was dealing with, and it was clear that unless they had available some such institution as the National Physical Laboratory, the Aerodynamics Department of which was housed within the same grounds as other departments, it would be difficult to carry such work through to success. If a worker there wanted to know anything about optics he had merely to cross from one building to another; if he wanted to know anything about thermometry he went to the thermometry department; and so on. It was the combination of these various departments of work, together with Mr. Fage's skill, that had enabled him to produce the material for his paper.

THE BEHAVIOUR OF FLUIDS IN TURBULENT MOTION

BY

A. FAGE, A.R.C.Sc., F.R.Ae.S.

(1) *Introduction.*—The internal motion of a fluid assumes one or other of two distinct forms; either the elements follow one another in a direct and simple manner, or else they wander about in erratic paths as they progress downstream. In the first kind of motion, called "regular" or "streamline," the components of the velocity at any selected point are either constant, or vary in a definite manner directly related to the boundary motions. In the second, known as "turbulent," these components continually change in an irregular way, which cannot apparently be connected with the regular boundary motions.

The essential features of these two motions were clearly revealed many years ago in a series of beautiful experiments by Osborne Reynolds.[1] Drops of colouring matter were added to clear water flowing in a glass pipe. When the

flow was streamline, the colour was drawn into even colour bands, whereas when the flow was turbulent the colour streaks curled and whirled about in an indefinite manner.

Laminar flow near the mid section of a flat plate at a wind speed of 20ft. per sec. Magnification 0.8.

Turbulent flow near the mid section of a flat plate at a wind speed of 40ft. per sec. Magnification 0.8.

Turbulent flow induced artificially by a circular wire of 0.05*in. dia. placed across the surface 2in. forward of the mid section. Magnification* 0.8.

FIG. 1.

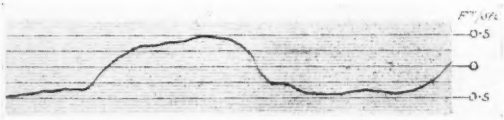
(2) Turbulence in a fluid stream occurs either in localised masses or in general diffusion. The first state exists in the vortex street behind a bluff obstacle, and the second in a turbulent boundary layer adjacent to the surface of a streamline body, in the distant wake of a moving body, and in the flow in a pipe at high Reynolds number. It is turbulence in a diffused state, or as it is often called, completely developed eddying motion, of which I wish to speak this evening.

Contemplation of the mysteries of this state of flow inspired Osborne Reynolds to deliver his famous panegyric on the importance of making fluid flow visible. If anyone has any doubts as to the wisdom of this advice, he would have had such doubts removed had he been present at Mr. Farren's lecture on "Airflow," given to the Society about a year ago.[2] You will recollect that Mr. Farren then exhibited an apparatus with which airflow was made visible, by means of white smoke from titanium tetrachloride, and the patterns revealed were projected on a screen. I have no such fascinating pictures to show this evening, for the features of flow on which I am to speak are not so readily portrayed. I would, however, like to show you some smoke photographs

obtained at the N.P.L. by Mr. Simmons,[3] who has devoted considerable attention to the art of smoke photography, to illustrate the essential features of eddying motion. The photographs (Fig. 1) give streamline and turbulent flows in the boundary layer of a flat plate held edgewise to the oncoming stream. You will

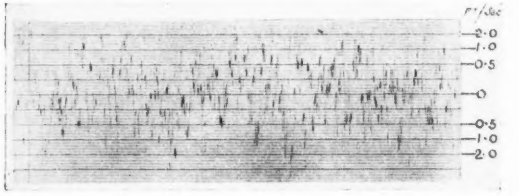
Flow in the boundary layer of an airship model.

(*a*) *Record of speed variations in the duplex wind tunnel during an interval of* 0.6 *second, at a wind speed of* 20*ft. per second.*



(*b*) *Record of speed variations during* 0.6 *second in the forward part of the boundary layer of an airship model.*

(*c*) *Record of speed variations occurring at a point* 14*in. forward of the position of breakdown.*



(*d*) *Record showing the speed variations in the rear end of the boundary layer, where the flow has become turbulent.*

FIG. 2.

notice that the eddying flow is characterised by great agitation, and there is no apparent regularity in the flow structure. On the other hand, the smoothness of flow in the streamline motion is most apparent.

(3) The smoke photographs give the impression that in eddying flow the speed and direction of the fluid at any point change continually with time. If now a fine platinum wire of small heat capacity were held in the fluid stream, and heated electrically by applying a constant E.M.F. between its ends, the

temperature, and so the electrical resistance of the wire, would depend on the speed of the stream. We should expect then the current through the wire to change in step with the speed. Records of velocity fluctuations in the boundary layer of an airship model obtained in this manner by Mr. Simmons[4] are given in Fig. 2. The disturbed character of the flow in a turbulent boundary layer is again clearly indicated.

(4) Most flows occurring in nature are turbulent. Diffused turbulence inevitably arises in the motion of aircraft. Apart then from an interest in the subject itself, it is a matter of some importance to those engaged in design to obtain clear ideas on the origin and nature of this motion, for such knowledge should ultimately lead to better aircraft.

Mathematical methods have so far failed to reveal the actual internal motions of eddying fluids. Some attempts have been made to determine the state of flow in the neighbourhood of flat plates and circular cylinders, but the solutions obtained have failed to indicate the commencement of eddying motion. The only direct prediction of the birth of eddying motion from the equations of motion is that due to G. I. Taylor.[5] The state of disturbed motion in the space between two concentric cylinders rotating at different speeds was considered. Taylor predicted that under certain conditions a series of vortex rings lying between the cylinders like anchor rings with their axis coincident with the common axis of the cylinders would be developed. Interesting information on the nature of vortices was obtained, and the theoretical conclusions of the analysis were confirmed by observation. The anchor ring régime marks the inception of turbulent flow, for a state of diffused eddying motion was rapidly established as the speed was slowly increased.

In view then of the failure of theoretical methods to obtain information on obscure details of eddying flow, we are compelled to resort to direct observation and measurement. Even then the task is not easy, for it is often difficult to perceive and describe the exact manner in which the elements move.

(5) *The Cause of Eddies.*—Although it is my intention to deal with completely developed turbulence only, it is well to consider for a moment the origin of turbulence. In 1843 Stokes advanced the view that turbulence arises from the fact that under certain conditions a steady motion becomes unstable, so that a small disturbance leads to a change to sinuous motion. Attempts have therefore been made to predict the birth of turbulence by considering under what circumstances a small disturbance superimposed on the general motion will increase or decrease, or the energy of an arbitrary disturbance will increase or decrease: unfortunately with little success. Nevertheless, observation leaves little room to doubt that turbulence does originate when the steady motion is unstable, if not to small at least to large disturbances. Osborne Reynolds is very clear on this matter. He says, speaking of the critical flow in a pipe, " I had expected to see the eddies make their appearance as the velocity increased, at first in a slow and feeble manner, indicating that the water was but slightly unstable, and it was a matter of surprise to me to see the sudden force with which the eddies sprang into existence, showing a highly unstable condition to have existed at the time the steady motion broke down."

(6) Let us take another point of view. We know that the flow pattern around a body depends on the ratio of the product of a linear dimension (l) of the body and the velocity (v) of the fluid to a physical property of the fluid, the kinematic viscosity ν; or as we now say, in honour of the great pioneer, on Reynolds number (vl/ν). We also know that with all bodies a change from streamline to turbulent flow occurs over a critical range of the value of this number. It is easy to see why Reynolds number plays such an important *rôle*, if we write

$$vl/\nu \text{ varies as } \tfrac{1}{2}\rho v^2/(\mu v/l) \text{ varies as } \frac{\text{dynamic force}}{\text{viscous force}}$$

At low values of vl/ν, the state of motion is controlled by viscous forces, so that disturbances are damped out and the flow is steady. As vl/ν increases, the dynamic forces become more powerful so that disturbances are not so easily damped out and eventually eddying sets in. We see then that the more viscous a fluid the less likely is steady motion to be disturbed under any circumstances. On the other hand, high speed and large size are conducive to unsteadiness.

(7) So far, I have touched briefly on some of the more common features of eddying flow. I now wish to dwell on some of the less apparent features. Obviously, the structure of the flow will be influenced by the presence of a solid wall, and I consider first the conditions at a solid boundary of a fluid in eddying motion. Afterwards, the mechanism of " free " eddying motion, that is, eddying motion not influenced by solid walls, will receive some attention.

The Conditions at the Boundary of a Fluid in Eddying Motion

(8) *Gradient of Mean Velocity.*—The flow near a solid wall is intimately connected with the friction on its surface. What do we know of the mechanism by which the resistance to flow is transmitted to the wall?

The behaviour of the fluid when the general motion throughout is streamline in character is clearly understood. The classic experiments of Poiseuille on the flow of fluids through glass tubes of fine bore showed that the time of efflux of a given volume of fluid was the same as that determined from the theory of streamline flow, on the assumption that the fluid in contact with the wall of a tube was at rest relative to it. It was suggested at that time that the efflux might be influenced by the nature of the surface, but all doubts were removed when careful experiments of Whetham[6] showed that no slip occurred between a surface and a fluid in streamline motion, if the surface was wetted by the fluid. The intensity of surface friction (f) is then given by the relation $f=\mu\,(\partial V/\partial y)_{y=0}$, where V is the velocity parallel to the surface at a distance y from the surface, and μ is the coefficient of viscosity.

(9) When the general motion is turbulent, the mean velocity falls rapidly as the distance from the surface diminishes. Viscous forces then become more powerful and it has been suggested that the flow simulates more and more closely the streamline character, as the surface is approached. The surface friction would then be equal to the product of the gradient of mean velocity at the surface and the coefficient of viscosity. Careful measurements were made by Stanton[7] to ascertain whether such a relation held for the eddying flow through a pipe. The measurement of the surface friction did not present any difficulty. It was however an extremely difficult matter to obtain accurate measurements of the mean velocity very near the wall of the pipe. Eventually, however, an ingenious surface tube, which had for its inner wall the surface of the pipe, was designed, and Stanton was able to make measurements of the mean velocity at points which were only about 0.002in. from the surface. A series of faired curves taken from Stanton's paper are given in Fig. 3. These curves show the variation of mean speed with the distance from the surface, at constant values of the surface friction (f). The dotted curves give the velocity gradient at the surface calculated from the relation $f=\mu\,(\partial V/\partial y)_{y=0}$, for the measured values of f and μ. Each full-line curve appears to tend to a definite slope at the boundary which is identical with that given by the relation

$$f=\mu\,(\partial V/\partial y)_{y=0} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

It will, however, be noted that even although the values of V nearest the surface were taken at a distance of only 0.002in. yet they fall some distance from the dotted curves. Nevertheless, a reasonably close approximation to the value of the surface friction can be obtained from measurements of the mean velocity taken with a Stanton tube. This method of predicting surface friction was used by Mr. Falkner and myself[8] in some recent experiments on a large aerofoil. We

found that the frictional drag of the aerofoil obtained from an integration of the measured frictional intensities was in fairly close agreement with the values obtained by two other independent methods. The work which has been done with Stanton tubes leads us then to the conclusion that in eddying flow the gradient of mean speed tends to a definite value at the boundary which seems to be identical with that for a streamline motion which has the same friction on the surface. Does this imply that in turbulent motion there exists at the boundary a layer of fluid of small but finite thickness, within which the motion can be taken as streamline? An answer to this question can be obtained by watching the antics of particles very near the surface. Let us see what further observation has revealed.

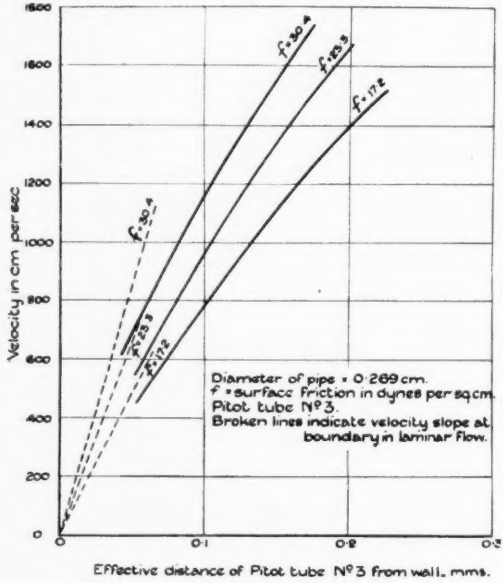


FIG. 3.

(10) *Visual Examination of Flow.*—The methods used to obtain visual impressions of fluid flow with which we are most familiar involve the introduction into the fluid of particles of foreign matter such as aluminium particles, oil drops, etc. Near a wall the disturbances are very small, and we are only sure that a faithful picture of the internal motions is obtained when neither extraneous particles nor measuring instruments are introduced into the fluid. After some consideration it occurred to me that examination with an ultramicroscope should afford a possible means of avoiding any interference with the flow, and eventually with the valuable help of Dr. Townend this method was made to yield some interesting information on minute details of eddying flow.[9] Since the publication of our work we have discovered that Nisi and Porter[10] had previously used an ultramicroscope to examine the flows behind small cylinders and flat plates, but we can claim, I hope, that the technique of measurement which we developed is novel.

(11) The principle of the ultramicroscope depends on the fact that minute particles usually present in most fluids, but invisible in ordinary light even under the most powerful microscope, become visible when intensely illuminated, provided they are seen against a dark background. Particles whose shapes are

not discernible, because they are smaller than the wave-length of light, then become visible as bright points of light. At first, we thought it would be necessary to use distilled water to which a small quantity of some colloidal solution had been added, but this proved to be unnecessary since a preliminary test showed that ordinary tap water contained a sufficient number of particles for the purpose of observation.

(12) The flow through a long square pipe of side 0.89in. was selected for examination. Observation was made above the critical speed and at a distance of about 4ft. from the mouth of the pipe, where the eddying motion was completely established. The water was illuminated through a window let into one side of the pipe, and observation was made through a window in an adjacent side. This second window overlapped the first, so that particles in the immediate

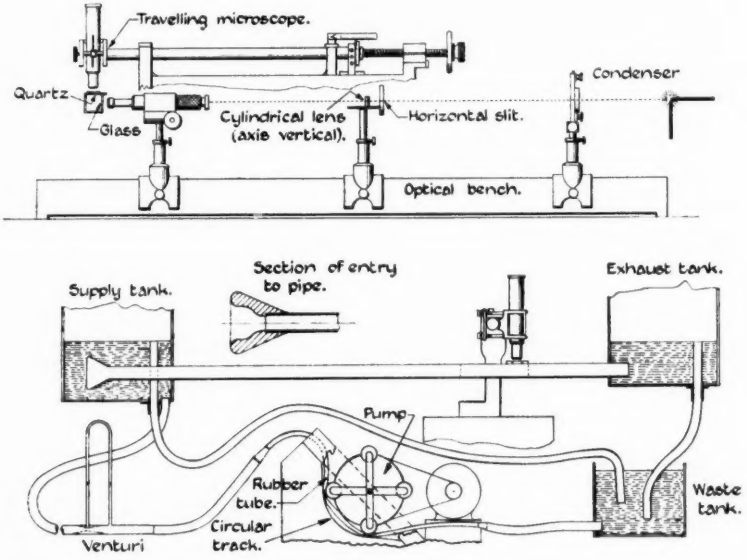


FIG. 4.

neighbourhood of a surface could be illuminated and observed. Sketches of the water and illuminating systems are given in Fig. 4. The light from a small arc lamp was brought to a focus by a single condensing lens and passed through a compound lens and a glass window into the water. A small cylindrical lens was interposed between the image of the arc and the compound lens to convert the conical incident beam into a wedge-shaped beam. The width of the beam of illumination was thus increased up to the diameter of the field of the microscope, without an increase in depth. To allow the height of the incident beam to be adjusted, the lens system was mounted on an optical bench, pivoted at the arc lamp end and provided with a screw adjustment at the microscope end. This adjustment, in conjunction with the lateral and vertical movements of the microscope, enabled a complete quadrant of a cross-section of the pipe to be explored.

(13) Since the general motion was eddying, there was at any fixed point a succession of irregular motions crossing the pipe in different directions. If now the radii of curvature of the sinuous paths of the particles are large compared with the diameter of the field of the microscope, only short lengths of the paths

will be seen when the particles are illuminated. These short lengths will appear as bright rectilinear streaks inclined at various angles to the mean direction of flow, and at high speeds, owing to the persistence of vision, they will appear to intersect each other. Such was the view seen at the central region of the pipe (see Fig. 6). Naturally we were interested to know how the obliquities of the streaks changed with the position in the pipe. To measure these obliquities, a fine platinum wire, which was carried on prongs connected to the eyepiece and which could be rotated about the axis of the microscope by means of a pointer moving over an angular scale, was mounted in the focal plane of the eyepiece. To facilitate observation the wire was rendered luminous by electrically heating it to a dull red glow.

(14) The measurements made in the pipe were referred to a rectangular system of axes XYZ. The axis OX was taken coincident with the axis of the pipe, the axis OY was horizontal and normal to one side of the pipe, and OZ was vertical. The mean axial velocity at a point was denoted by U, and the components* of the disturbed velocity by u, v and w. The actual velocity components at any instant were therefore $U+u$, v and w. A particle viewed normal to the plane XOY appeared then to be moving in a direction inclined at an angle $\tan^{-1}\{v/(U+u)\}$ to the axis of the pipe, and if viewed normal to the plane XOZ in the direction $\tan^{-1}\{w/(U+u)\}$. It is apparent that to define completely the turbulence, it would be necessary to take continuous records of the velocity components u, v and w, or alternatively of u, θ_{xy} and θ_{xz}, where

$$\theta_{xy,\,xz} = \tan^{-1}\{v,\, w/(U+u)\}.$$

This appeared to be an impossible task. We were, however, able to obtain fairly reliable measurements of the maximum values of θ_{xy} and θ_{xz} (denoted by Θ_{xy} and Θ_{xz}) and also of the maximum value of u (denoted by u_1) at any point in the fluid, except near the boundary. We also observed that the velocity components v_1 and w_1 appeared to be out of phase with u_1. Values of v_1 and w_1 were therefore predicted from the relations

$$v_1,\ w_1 = U \tan(\Theta_{xy},\ \Theta_{xz}) \qquad . \quad . \quad . \quad . \quad (2)$$

It was possible, therefore, to obtain the maximum values of the three components of the velocity disturbance at a point in the fluid, and the ratios of these values (u_1, v_1 and w_1) to U were taken as a measure of turbulence.

(15) Let me now describe briefly the method of measuring U and u_1. We did not wish to introduce any instrument into the fluid, and so we had to seek a method which would allow the path of a particle to be followed from outside the pipe. Evidently, a particle would appear as a bright stationary point instead of a streak, if the microscope were moved with the speed of the particle. The same effect can however be obtained, over a limited area, if the eyepiece and the microscope tube are fixed and the objective is moved in the same direction as the particle. A sketch showing the microscope fitted with a rotating objective is given in Fig. 5. The objective A was carried on a horizontal spur wheel B which could be rotated about an offset vertical axis C. Once in every revolution the optical axis of the objective coincided with that of the microscope tube, and the position of the bracket D was adjusted so that at the instant of coincidence the direction of motion of the objective was parallel to the axis of the pipe. The factor for obtaining the translational speed of a particle brought to apparent rest from the rotational speed of the objective was obtained by direct calibration.

The illuminated region of the field was only visible for a small part of each revolution of the objective so that a series of snapshot views were seen. The appearances of some of these snapshots are sketched in Fig. 6 (*f*)-(*i*), for various speeds of the particles and the objective. If the flow were streamline, the views

* Sign included.

at the centre of the pipe show simply a group of points, when the speed of rotation corresponds to the speed of flow. Actually, the slight curvature of the path of the objective, whilst crossing the illuminated region, causes the points to be drawn out into very short streaks normal to the axis of the pipe. In

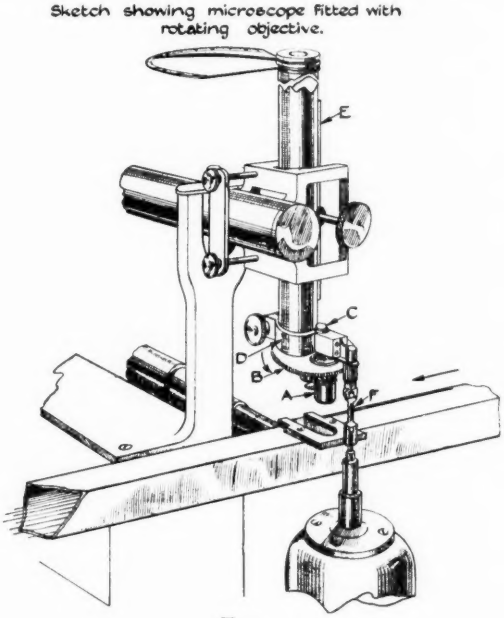


FIG. 5.

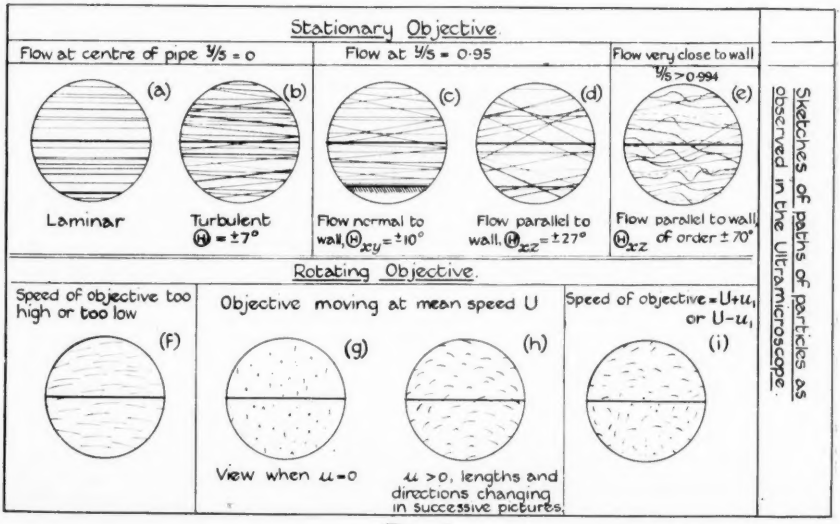

Stationary Objective.
Flow at centre of pipe y/s = 0
Flow at y/s = 0·95
Flow very close to wall
y/s > 0·994
(a)
(b)
(c)
(d)
(e)
Laminar
Turbulent
Θ = ±7°
Flow normal to wall, Θxy = ±10°
Flow parallel to wall, Θxz = ±27°
Flow parallel to wall of order ± 70°
Rotating Objective.
Speed of objective too high or too low
Objective moving at mean speed U
Speed of objective = U+u1 or U−u1
(f)
(g)
(h)
(i)
View when u = 0
u > 0, lengths and directions changing in successive pictures.
Sketches of paths of particles as observed in the Ultramicroscope.

FIG. 6.

turbulent motion, the successive views differ, on account of the fluctuations in the velocity of the stream. The views then show streaks of different length and direction, when the objective rotates at the speed corresponding to the mean speed of flow. Points, or vertical streaks, which indicate that the velocity component u is zero, were therefore only occasionally seen. At any point in the fluid, the velocity component $(U+u)$ fluctuates continually between the limits $(U \pm u_1)$, so that particles only appear as points or as short streaks normal to OX, provided that the corresponding speed of the objective lies between these limits. Hence the value of $(U-u_1)$ was obtained by slowly increasing the speed of the objective until " stationary " particles (or streaks normal to OX) first appeared, and the value of $(U+u_1)$ by increasing the speed further until they just ceased to appear.

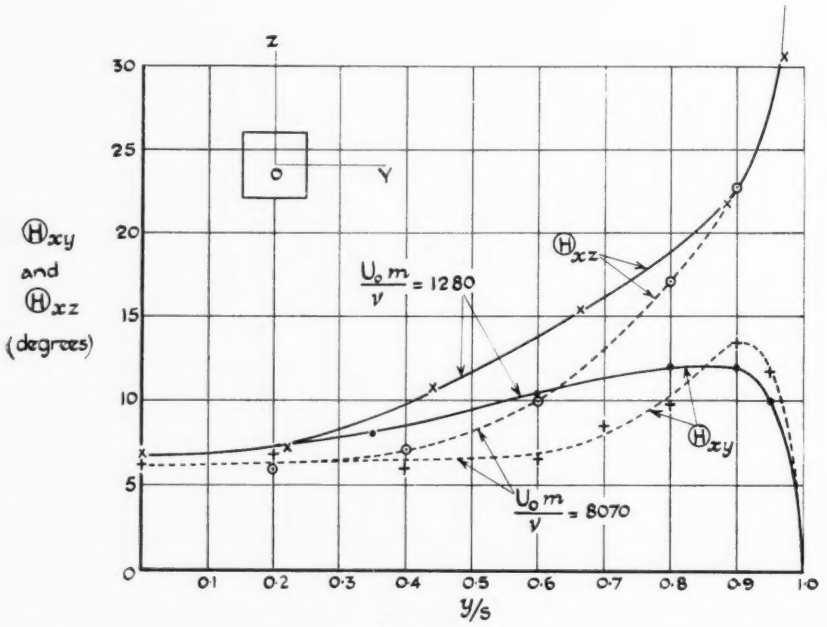


FIG. 7.

(16) *Flow Observed Near the Wall.*—Some observations of Θ_{xy} and Θ_{xz}, taken on the axis OY at two values of U_0m/ν, are plotted against y/s in Fig. 7.[11] The value of Θ_{xy}, *i.e.*, the maximum obliquity in the plane XOY, slowly increases with the distance from the axis of the pipe, until a maximum is attained at about $y/s=0.9$. The value then falls steadily to zero at the wall. The particles seen when looking along and *very close* to the wall appeared therefore to be moving in laminæ parallel to the wall.

The values of Θ_{xz} reveal the surprising phenomenon that the maximum obliquity in planes parallel to the wall increases continuously as the wall is approached. Indeed, at a distance of 0.003in. from the wall Θ_{xz} reached the large value of about 70°.

How does the value of Θ_{xz} change with a closer approach to the wall? To obtain an answer to this question the flow in the immediate neighbourhood of the wall was viewed with a microscope of very high magnification (200).

Illuminated particles within a layer of thickness 0.001in. were then in focus. The view obtained showed a large number of particles moving in sinuous paths, and a few slower ones which appeared to be moving in rectilinear paths. No reliable measurements of Θ_{xz} could be made since the paths were mostly curved, and in fact paths of a wavy form were frequently seen. An attempt was made to determine how near to the surface sinuous paths were to be observed. The distances involved were too small to be measured directly, and they were accordingly predicted from measurements of the velocity of particles which were slow enough to be timed across the field (of diameter 0.03in.) with a stop-watch, and a value of the velocity gradient at the surface obtained from the

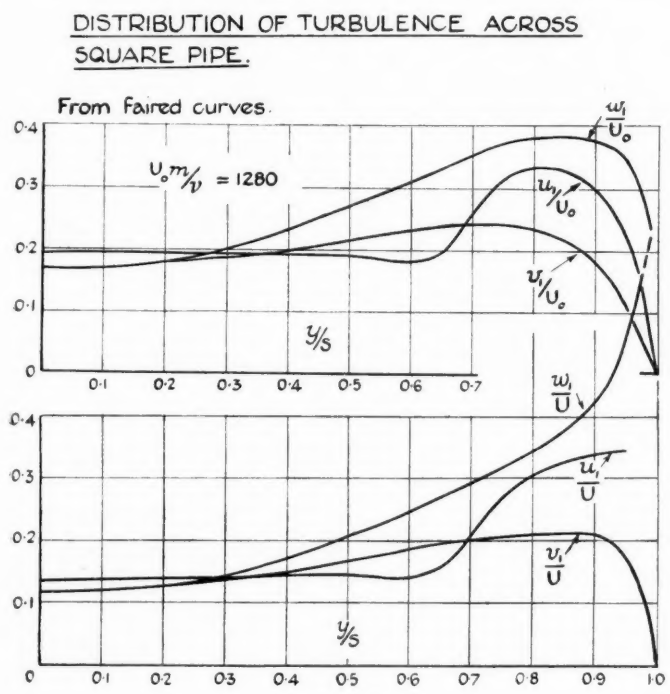


FIG. 8.

known surface friction. It appeared that some of the slowest particles observed were at a distance of only 1/40,000in. from the surface. We thought at first, that these particles were moving in rectilinear paths, but on inserting a hair-line in the eyepiece of the microscope, it was noticed that all such particles moving near the hair-line usually crossed and re-crossed several times. We spent a considerable time watching these particles and came to the conclusion that no particle was ever seen about which it could be said with conviction that its motion was rectilinear.

Faster particles could be observed at the same time as the very slow particles at the surface on account of the finite thickness of fluid (0.001in.) within the focus of the microscope. A group of these faster particles occasionally made relatively large lateral excursions, and then the slowly moving particles would also shift laterally. Sometimes two or more slowly moving particles, often widely separated, were observed to shift in step, and the whole appearance

suggested that the violent motion in the faster moving fluid dragged the whole surface layer bodily sideways. Smaller lateral motions should also drag the surface layer sideways, but the shift might be too small to be observed, and then the flow during the intervals between the large excursions would appear to be rectilinear. No velocity fluctuations were observed in any part of the fluid below the critical speed, and the flow at the surface was rectilinear.

(17) We are thus led to the conclusion that when the general motion is eddying the conditions of flow very near the surface are not the same as those which exist in a streamline flow which gives the same friction on the surface. The tacit assumption made in some theories of turbulent motion, that there is a thin layer of streamline flow in contact with a plane surface within which the particles are in rectilinear motion, does not seem to be consistent with the facts, even although there is no reason to doubt that the friction on the surface is

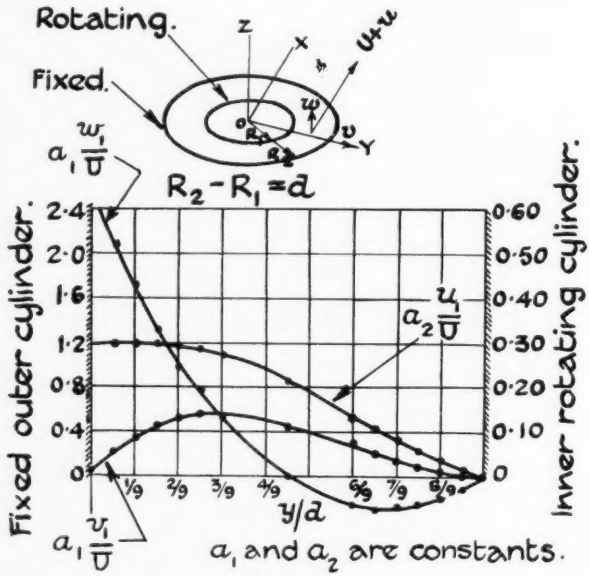


FIG. 9.

closely given by the relation $f=(\partial V/\partial y)_{y=0}$, where V is the mean velocity at a distance y from the surface.

(18) *Turbulent Velocities in a Pipe.*—Representative distributions of the turbulent velocities u_1, v_1 and w_1 across a pipe are given in Fig. 8. In the top diagram, faired curves are drawn which give u_1/U_o, v_1/U_o and w_1/U_o, where U_o is the mean rate of flow through the pipe, against y/b, the distance from the axis divided by the half width of the pipe. The three components u_1, v_1 and w_1 of the disturbed velocity have fairly uniform values over the central region of the pipe. With a closer approach to the wall they first rise to maximum values, and then tend to zero at the wall itself. The curves in the lower diagram give the variations of the ratios u_1/U, v_1/U and w_1/U, where U is the mean local speed, with (y/b). It will be observed that u_1/U tends to become constant as the surface is approached, w_1/U increases to a maximum at the surface itself, and v_1/U decreases to zero.

(19) Professor Taylor[9] has made an examination of the significance of our measurements of u_1/U, v_1/U and w_1/U, which has led to some interesting sug-

gestions on the mechanism of flow very near a surface. He shows mathematically that the vortex system which forms in a viscous fluid between two cylinders, when the inner one is rotated whilst the outer one is at rest, exhibits the characteristic features which we observed in the neighbourhood of the wall of a pipe. The curves of u_1/U, v_1/U and w_1/U calculated for this régime are given in Fig. 9. The likeness of these curves to those of Fig. 8 is very apparent. Professor Taylor does not suggest that the disturbances between the concentric cylinders are similar to those at the wall of the pipe, as might at first sight appear to be the case, but he says, " It seems legitimate to suppose that the cause which gives rise to the characteristic distributions of u_1/U and w_1/U close to the surace in the case of the rotating cylinders is the cause which produces identical characteristics in the observed distributions, namely, the existence of transverse local pressure gradients at the surface." Further, a theoretical consideration of the motion near a wall in which the disturbed velocity as well as the mean velocity is two-dimensional indicates that the special features of the observed motion may be associated with the existence of fluctuating pressure gradients at the surface transverse to the mean direction of flow which may

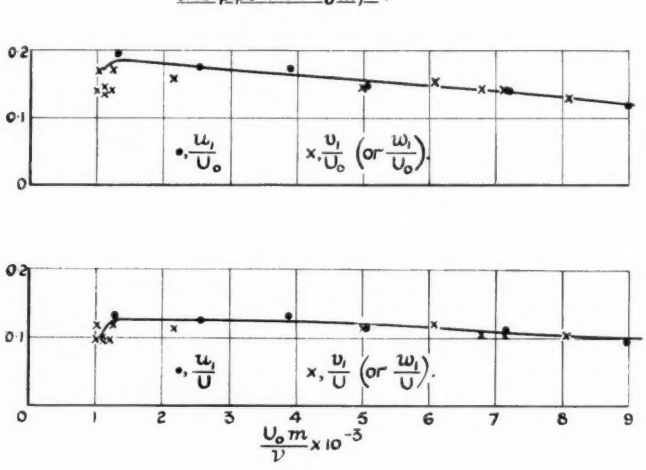


FIG. 10.

be large compared with the fluctuating pressure gradients in the direction of mean flow.

(20) It has been convenient so far to confine attention to the conditions of turbulent flow near the wall of a pipe. Several interesting features of flow were also observed in the central region of the pipe. Values of u_1/U and v_1/U (and w_1/U from symmetry) measured on the axis of the pipe are plotted against the Reynolds number $U_0 m/\nu$, where m is the hydraulic mean depth, in Fig. 10.[11] These values are seen to lie closely on the same curve. The transverse velocity disturbances on the axis are therefore equal to the axial disturbances. The magnitude of these disturbances falls slowly with an increase in Reynolds number.

It will be seen in Fig. 7 that equality between Θ_{xy} and Θ_{xz}, that is between v_1 and w_1, exists not only on the axis but over an appreciable central region. Curves of Θ_{xy} and Θ_{xz} for a high and also a low value of $U_0 m/\nu$ are given in this figure. The appearance of these curves suggests that the central region,

over which equality between Θ_{xy} and Θ_{xz} exists, is greater at the higher value of $U_o m/\nu$.

Theories of Eddying Motion

(21) *Theories of Eddying Motion.*—I will now dwell on certain aspects of "free" eddying motion, that is, eddying motion which is not influenced by the presence of solid boundaries. A common flow of this character, and one which is of interest to the aeronautical engineer, is that which exists in the wake at some distance behind a moving body. There are at present two theories of eddying motion, the Momentum Transport Theory of Prandtl and the Vorticity Transport Theory of Taylor. Outlines of these theories will now be given, to indicate the trend of modern opinion, and to give an insight into possible motions of the fluid elements. It will be apparent that the mechanism controlling the behaviour of eddying motion is still somewhat obscure, and that there is a need for further experimental evidence on the structure of such motion. Fortunately, an endeavour is now being made both in this country and abroad, to satisfy this need. Let me just refer to the work now in hand at the N.P.L. Messrs. Simmons and Salter are using exceedingly fine hot wires to obtain information on the structure of eddying flow. Dr. Townend has developed a technique in which a periodic electric spark is produced in a stream and the motions of shadows of the small masses of hot air as they pass downstream are continuously photographed. Further examinations of turbulent flow with an ultramicroscope are also in progress.

(22) *Prandtl's Theory.*—This theory is based on a conception due to Osborne Reynolds[12] that the instantaneous velocity at a point in a fluid can be divided into two parts, namely, a mean velocity and a fluctuation about the mean. If then the flow is two-dimensional in the plane XOY, the components of the instantaneous velocity parallel to the axes OX and OY may be written $U+u$ and $V+v$, where U and V are the components of the mean velocity, and u and v the components of the fluctuating velocity. Hence it can be shown that if planes are taken through the point normal to the axes OX and OY, the apparent normal stresses will be $F_{xx}=-\rho\overline{u^2}$ and $F_{yy}=-\rho\overline{v^2}$ respectively, and the apparent tangential stress $F_{xy}=-\rho\overline{uv}$, where ρ denotes the density and the bar average time values.

(23) The essence of Prandtl's theory[13] is that expressions are obtained for the apparent tangential stresses set up by the convective motions, in a form which allows the differential equations of the mean motion to be solved. In other words, the prediction of turbulence phenomena from these equations is made possible by the application of statistical methods.

Consider now the eddying wake behind a very long cylindrical body held at rest in a fluid streaming past it with a velocity U_o. Take the axis of symmetry in a plane normal to the length of the body. Let the distance perpendicular to the axis OX be denoted by y. The components of the instantaneous velocity at a point in the eddying wake is then $(U+u)$ and $(V+v)$, where U and V are the components of the mean velocity, and u and v the components of the fluctuating velocity. Prandtl assumes the eddying motion to be controlled by the shearing stress $F_{xy}=-\rho\overline{uv}$, and a value for this stress is obtained in terms of the gradient of mean velocity and a quantity (l), which he calls the "Mischungsweg," that is, "mixing distance." Actually, an element of the fluid at some point P, where the mean velocity is U, is considered to move across the wake a distance l, without any change of mean velocity, to a point P'. On arrival at the point P' the element is conceived to mix with the surrounding fluid. If l is small the mean velocity at P' is $U+l\,(dU/dy)$, so that the displaced fluid element on arrival has a disturbed velocity u equal to $-l\,(dU/dy)$. Hence if we neglect the pressure

gradients in the fluid which accompany the eddying motions, the apparent tangential stress $F_{xy}=\rho\overline{vl}\,(dU/dy)$.

The rate at which momentum is communicated to unit area of a layer of thickness dy is then $\rho\,(d/dy)\,\{\,\overline{lv}\,(dU/dy)\,\}\,dy$, and if the flow is due to a uniform pressure gradient $d\bar{p}/dx$, we have

$$(d/dy)\,\{\,\overline{lv}\,(dU/dy)\,\}=(1/\rho)\,(d\bar{p}/dx) \quad . \quad . \quad . \quad (3)$$

(24) The quantity of $\rho\overline{lv}$ has the same dimensions as viscosity, and in Prandtl's theory it is treated as if it were an "apparent viscosity." Whilst however the coefficient of viscosity μ is a physical constant of the fluid, the apparent viscosity $\rho\overline{lv}$ varies from point to point and is a function of the velocity. Prandtl considers that the transverse velocity v may arise from the fact that two elements having different values of u and occupying positions in front of one another may collide or move away from each other. This leads to the assumption that the velocity v can be taken proportional to u, and the apparent tangential stress becomes

$$F_{xy}=\rho l^2\,|\,dU/dy\,|\,(dU/dy) \quad . \quad . \quad . \quad . \quad (4)$$

The straight bars surrounding dU/dy indicate that the absolute value is to be taken. The form of (4) allows therefore for a change of sign of F_{xy} with a change of sign of dU/dy. It is also apparent that the length l includes the proportionality factor of u and v, and also the correlation factor which appears in the calculation of the mean product.

The "apparent viscosity" or measure of momentum exchange is given, in its simplest form, by $\epsilon=\rho\overline{vl}=\rho l^2\,|\,dU/dy\,|$. When the velocity has a maximum value, the value of ϵ becomes zero, and to overcome this difficulty a second approximation of the form $\rho l^2\,\{\,(dU/dy)^2+l_1{}^2\,(d^2U/dy^2)^2\,\}^{\frac{1}{2}}$ has been suggested.

(25) *The Mischungsweg.*—A great deal of attention has been given in Germany to theoretical predictions of the characteristics of the mischungsweg, from measurements of mean speed. This work has been described by Dr. Maccoll[14] in his recent lecture to the Society, and there is no need for me to dwell long on the subject. It is sufficient to say that some of the problems to which the theory has been applied are the diffusion of turbulence in the eddying wakes behind long cylindrical obstacles[15, 16] and bodies of revolution,[17] and in the region of separation between moving and stationary streams.[18] It would appear from these and other investigations that the mischungsweg provides a method of correlating experimental observations of mean speed. The mischungsweg is a correlation factor only, and not a physical quantity.

In general, it is assumed that the motions in sections perpendicular to the direction of flow are mechanically and geometrically similar, and that the "mischungsweg" l is constant across the wake and proportional to its breadth. The apparent tangential stress then takes a form which allows the equations of motion to be integrated, and predictions of the magnitude of l to be made.

(26) More recently, von Kármán[19] has introduced a new conception of the mischungsweg. The conditions under which disturbances can be similar to each other are examined, when the states of flow in the neighbourhood of two points differ only in the scales of the disturbed velocities and of the length of the field of flow. These considerations lead to a characteristic value for the length scale of the disturbances, which is proportional to $(\partial U/\partial y)/(\partial^2U/\partial y^2)$; and to equality between the velocity components u and v at any point, which become proportional to $(\partial U/\partial y)^2/(\partial^2U/\partial y^2)$. The values of the coefficients of proportionality are determined from general considerations of tangential stresses. Obviously the above relations cannot be applicable in regions where either $\partial U/\partial y$ or $\partial^2U/\partial y^2$ is zero.

(27) *Taylor's Theory.*—A theory of turbulent flow which until recently appears to have escaped notice was advanced by G. I. Taylor[20] several years ago. This theory supposes that each element of the fluid retains the vorticity

of the layer from which it started. Apart from this essential difference, Taylor's theory resembles Prandtl's theory in that the element is supposed to move a distance " l " before mixing with the surrounding fluid. The reason why Taylor concentrated on the transference of vorticity rather than of momentum was that if the motion is confined to two dimensions, the local differences of pressure do not affect the vorticity of an element, whereas they may affect the momentum of individual elements of the fluid. Prandtl assumes that such pressure differences do not affect the mean transfer of momentum.

Taylor illustrates his theory[21] by considering the simple case in which the mean flow is parallel to the axis of x, and the whole motion is limited to two dimensions. The equation of motion, neglecting viscosity, is then

$$-(1/\rho)(\partial p/\partial x)=\partial u/\partial t+u(\partial u/\partial x)+v(\partial u/\partial y).$$

This expression becomes

$$-(\partial/\partial x)(p/\rho+u^2/2+v^2/2)=\partial u/\partial t+2v\eta,$$

if we write

$$\eta=\tfrac{1}{2}(\partial u/\partial y-\partial v/\partial x) \text{ for the vorticity.}$$

Taking mean values and assuming that the eddying motion is uniform in the direction of x we have

$$-(1/\rho)(\partial\bar{p}/\partial x)=2\overline{v\eta}.$$

The assumption is now made that the vorticity is conveyed from place to place without change until mixing occurs, and the correlation between η and v is obtained in the same way as the correlation between u and v in Prandtl's theory. A portion of the fluid which moves across the wake a distance l without any change of vorticity possesses a vorticity greater by an amount $-l(d/dy)(\frac{1}{2}dU/dy)$ than that of the layer with which it mixes, since the vorticity of the mean motion at any layer is $\frac{1}{2}dU/dy$. Hence $2\overline{v\eta}=-\overline{vl}(d^2U/dy^2)$, so that

$$(1/\rho)(dp/dx)=\overline{vl}(d^2U/dy^2) \quad . \quad . \quad . \quad . \quad (5)$$

The above relation is obviously identical with the relation (3) obtained by Prandtl, if $\overline{vl}$ does not vary with y.

(28) *Theories Compared.*—The rate at which momentum is communicated to unit volume is

$$M=\rho(d/dy)(\overline{vl}\,dU/dy), \quad . \quad . \quad . \quad . \quad (6)$$

according to the momentum transport theory of Prandtl, and

$$M=\rho\overline{vl}(d^2U/dy^2), \quad . \quad . \quad . \quad . \quad . \quad (7)$$

according to the vorticity transport theory of Taylor. Let us now endeavour to discriminate between these two theories. To do this it is not sufficient, as Professor Taylor has pointed out,[21] to take measurements of velocity and pressure alone, since on either theory a distribution of $\overline{vl}$ can be fitted to any set of measured velocities. An independent value of $\overline{vl}$ must be found. Fortunately, another estimate can be obtained from experiments on the transport of heat. For, if Q be the rate at which heat is transported across unit area perpendicular to OY,

$$Q=\rho\sigma\overline{vl}(\partial\theta/\partial y), \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where σ is the specific heat and θ the mean temperature at any point. A value for $\overline{vl}$ can therefore be predicted from measurements of Q and $\partial\theta/\partial y$.

Now expression (7) was obtained by Professor Taylor on the assumption that both the mean flow and the velocity disturbances are two-dimensional. The type of eddying flow for which predictions of the value of $\overline{vl}$ are to be made should therefore satisfy these conditions, and at the same time it must be one for which analytical solutions of the equations (6-8) can be obtained. The flow selected by Professor Taylor was that which occurs in the wake behind a long

cylindrical obstacle mounted with its axis normal to the general stream. We can consider later whether this type of flow satisfies all the conditions necessary for a strict comparison of the theories.

(29) The distribution of mean velocity in the wake behind a circular rod has recently been examined theoretically and experimentally by Schlichting.[16] At a downstream distance (x) greater than 30 diameters, the expanding wake settles down to a steady régime in which the velocity drop at the centre is proportional to $x^{-\frac{1}{2}}$, and the width to $x^{\frac{1}{2}}$. Schlichting found that his velocity results could be expressed in the form $(U_0-U)/U_0=x^{-\frac{1}{2}}f(y/\sqrt{x})$, where U_0 is the velocity of the undisturbed stream, and U and V the components of the mean velocity at a point in the wake. The corresponding value for V which satisfies the equation of continuity is

$$V/U_0=-\tfrac{1}{2}x^{-1}(y/\sqrt{x})f(y/\sqrt{x}).$$

If the wake is narrow, that is, if y is small compared with x, and if (U_0-U) is small compared with U_0, the dynamical equation of motion is

$$U_0(\partial U/\partial x)=(\partial/\partial y)(\kappa\,\partial U/\partial y),$$

according to Prandtl's theory, and

$$U_0(\partial U/\partial x)=\kappa\,\partial^2U/\partial y^2,$$

according to Taylor's theory, where κ is written for the coefficient of diffusion by turbulence (*i.e.*, $\overline{lv}$).

Solutions of both these equations can be obtained analytically, on the assumptions that $\kappa=Al^2\,|\,dU/dy\,|$, where A is a constant, and that the mixing length l is constant over any section and equal to $ax^{\frac{1}{2}}$, where a is a constant.

The solution of Prandtl's equation is then

$$(U_0-U)/(U_0-U_c)=(1-\xi^{3/2})^2,$$

and the solution of Taylor's equation is

$$(U_0-U)/(U_0-U_c)=(1-\xi^{3/2})^2,$$

where U_c is the value of U at the centre of the wake, and $\xi=y/Y$, where Y is the half-breadth of the wake.

The two solutions, expressed in the above form, are therefore the same. Actually, however, the value of (U_0-U) predicted on Taylor's theory is twice the value given by Prandtl's theory, for the same value of Aa^2. Now this parameter determines the thermal conductivity due to eddying, so that for a *given* velocity distribution, the temperature distribution in the wake of a heated obstacle is determined by a thermal conductivity which according to the vorticity transport theory is twice as great as the value required in the momentum transport theory.

(30) The equation of heat transport is

$$U_0(\partial\theta/\partial x)=(\partial/\partial y)(\kappa\,\partial\theta/\partial y), \quad . \quad . \quad . \quad . \quad (9)$$

where θ is the difference of temperature between any point in the wake and that in the main stream.

The solutions of this equation are

$$\theta/\theta_c=(1-\xi^{3/2})^2$$

according to the momentum transport theory, and

$$\theta/\theta_c=(1-\xi^{3/2})$$

according to the vorticity transport theory, where θ_c is the temperature elevation at the centre of the wake.

Prandtl's theory predicts therefore that the distributions of $(U_0-U)/(U_0-U_c)$ and θ/θ_c should be identical, whereas Taylor's theory predicts that they should differ appreciably.

(31) To discriminate between the two theories Professor Taylor suggested to the Aeronautical Research Committee that experiments should be made at the N.P.L. to measure the distributions of temperature and velocity in the wake behind a heated obstacle. These experiments were made by Mr. Falkner and myself,[21] with two obstacles. First, a long $\frac{5}{8}$in. circular rod mounted between the walls of a 3ft. wind tunnel, and second, a thin-walled copper cylinder with a lenticular section mounted in a 1ft. open-jet tunnel. Our measurements of $(U_0-U)/(U_0-U_c)$ and θ/θ_c for these obstacles are plotted against ξ in Fig. 11. It will be observed, first, that the values of $(U_0-U)/(U_0-U_c)$ lie closely on the curve $(1-\xi^{3/2})^2$, a result to be anticipated from the earlier work of Schlichting; and second, that the points representing the values of θ/θ_c are near the curve $(1-\xi^{3/2})$ predicted by the vorticity transport theory, and that they are far removed from the curve $(1-\xi^{3/2})^2$ predicted by the momentum transport theory.

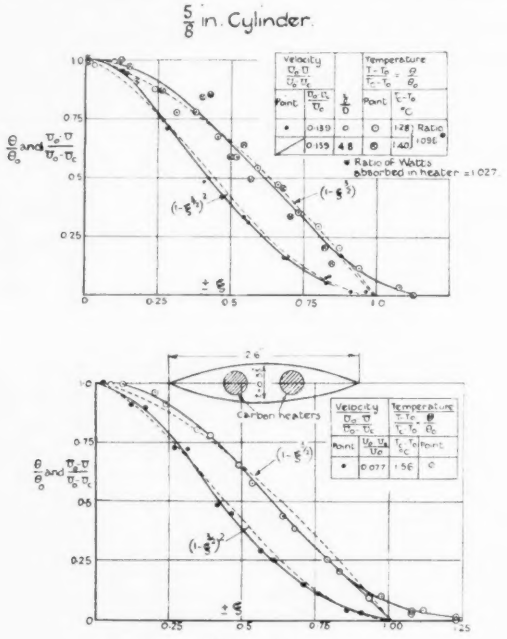


FIG. 11.

(32) A conclusion which may be drawn from the evidence in Fig. 11 is that the momentum transport theory does not hold for the type of flow selected. The failure to account for the observed results no doubt arises from the neglect of the theory to take account of the effect of the local variations of pressure. In fact, theoretical arguments are advanced by Professor Taylor to show that agreement between the two theories would only be expected when the turbulent motion is two-dimensional, and the disturbances are confined to planes normal to the direction of the mean motion.

On the other hand, support is given to Taylor's theory by the fairly close agreements obtained between the predicted distributions of temperature and velocity and those obtained by direct measurement. There is however good reason to believe, as we shall now show, that one of the conditions assumed in the theoretical predictions, namely, that the disturbances are confined to planes

normal to the length of the obstacle, was not realised in the experiments. Nevertheless, the evidence given in Fig. 11 does seem to suggest that the vorticity transport theory represents the facts much more closely than the momentum transport theory.

Disturbed Velocities in the Wake of a Body

(33) *Disturbed Velocities in the Wake of a Body.*—It is now generally accepted that the mean flow past a very long cylindrical body tends to be two-dimensional in planes at right angles to the length. Further, if the body has a bluff form the large disturbances in the Kármán vortex street, which is formed behind the body, are also largely two-dimensional. Are the disturbances in the diffused eddying motion arising from the breakdown of the vortex street also two-dimensional?

To obtain information on this question I examined with an ultramicroscope the eddying flow behind a long prism having a triangular cross-section.[22] The prism was mounted between the walls of a water tunnel, and with one side facing the on-coming stream in the manner shown in Fig. 12. The ratio of the length

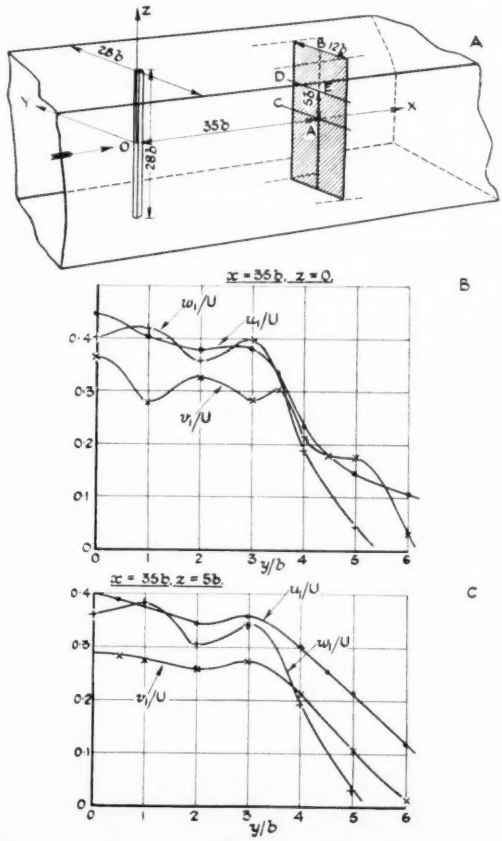


Fig. 12.

of the prism (l) to its cross-stream breadth (b) was 28.0. Observation was made over a region behind the central part of the prism, where the vorticity arising from the breakdown of the vortex street was completely diffused across the wake. At the outset, evidence was obtained from experiments with a relatively longer prism ($l/b=56$) that the character of the flow behind the original prism would not be appreciably modified by any practicable increase in its length. Also at the Reynolds number of the experiment it was shown that the flow had settled down to an established régime. The conditions of flow in the selected test could therefore be regarded as representative of those existing behind any long bluff body.

(34) The measurements to which I would now refer were taken in a plane normal to the general flow at a distance of $35b$ behind the prism. The system of axes selected is shown in Fig. 12. The origin O is taken at the centre of the side facing the stream. The axis OX is in the direction of the undisturbed stream; the axis OZ is in the direction of the length of the prism; and the axis OY is at right angles to both the direction of the stream and the length of the prism.

Observations of mean speed taken in this plane indicated that the mean flow behind the central part of the prism approached the two-dimensional type. Measurements of the maximum values of the three components of the disturbed velocity, denoted by u_1, v_1 and w_1 were made at points in the lines AC ($z=0$) and DE ($z=5b$). The ratios obtained on dividing these values of the disturbed velocities by the local mean speed U, are plotted in the lower diagrams B and C of the figure.

It will be observed that there is a fairly wide band behind the central part of the prism within which the values of u_1/U, v_1/U and w_1/U remain fairly constant. Outside the central band, these values fall gradually to zero as the outer limits of the wake are approached. Average values within the band, taken along the line AC, are $u_1/U=0.40$, $v_1/U=0.32$, $w_1/U=0.40$. The three-dimensional character of the disturbances in the wake is thus clearly demonstrated.

(35) The experiments on the long prism lead us to believe that, in general, the disturbances in the eddying wake behind any long bluff obstacle will be three-dimensional. Let us now speculate on the probable character of the turbulence in the wake of a long streamline body along which the boundary layer is turbulent. It is highly probable that the turbulence in the boundary layer will resemble that in a pipe, and if this is so, the values of the ratios w_1/U and u_1/U near the surface will be large compared with that of v_1/U, whilst at some distance from the surface the values of u_1, v_1 and w_1 will tend to be the same. Since the boundary layer leaves the surface fairly smoothly the disturbed velocities u_1, v_1 and w_1 at a point in the wake will have closely the same magnitude. It would seem, therefore, that the disturbances in the wake behind a very long streamline body will be three-dimensional. We arrive then at the interesting conclusion that the disturbances in the eddying wake behind any long body, bluff or streamline, placed with its length normal to the stream will be three-dimensional, if the Reynolds number is sufficiently high, even although the mean flow in planes at right angles to the length tends to be two-dimensional.

(36) In conclusion, let me say that I am very conscious that I have touched on only a few aspects of turbulent motion. I shall, however, feel content if one or two new features of flow have been brought to your notice.

I am indebted to the Aeronautical Research Committee for permission to make reference to a recent experiment, the results of which have not previously been published.

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Discussion

Professor G. I. Taylor: He complimented Mr. Fage upon a remarkably clear description of difficult work. For many years the methods of measuring the mean flow of fluids had been fairly satisfactory; when one came to measure evanescent flows, the introduction of smoke, coloured fluids, and so on into the water or air was very useful for qualitative results, but for quantitative results one must introduce something else into the water. Professor Jones and Mr. Farren had made some very elaborate measurements with oil drops introduced into the water. Even those oil drops, however, were too big to enable one to measure what happened very close to the wall; a great many people must have wondered how to get over this difficulty, and it was very remarkable that the answer was there all the time if only we had thought how to see it. The little particles needed were present in fact in all ordinary tap water; all that had to be done was to find out the method of seeing them, and Mr. Fage had shown how this can be done.

The first striking result put forward by Mr. Fage was the fact that the turbulent motion close to the surface was in the main transverse to the direction of mean motion. That was a nasty one for the mathematicians who had been working on the subject so far; an immense amount of effort had been expended in all parts of the world, and in Germany particularly, in endeavouring to describe mathematically the conditions near the wall along which a fluid was flowing, but all the mathematicians had considered that the flow was two-dimensional and that there was no transverse flow. It appeared, therefore, that they would have to start again.

The next result was the very remarkable tendency for the three components of turbulent motion towards equality. In Fig. 7 of the paper it was particularly striking in the case of the higher value of $U_0 m/\nu = 8070$. The two dotted lines representing the two components joined together at half the radius, and all the centre part was remarkably uniform or isotropic in regard to turbulence. That property towards isotropy of the turbulence, *i.e.*, towards equalisation of the turbulence in three directions, had been much discussed in meteorology in the past. Many years ago he had made a wind vane. This described a pattern on a piece of paper; when the vane was near to the ground the pattern was very elongated, but as it went up there was a tendency towards equality of cross wind and vertical components. He had also carried out work of the same kind in regard to the components longitudinally. From his observations it had appeared that there was a strong tendency to equality of turbulent motion and Mr. Fage's experiments appeared to show the same thing. For that reason he did not

believe for a moment that the theory put forward by himself and used by Mr. Fage, which theory depended upon the assumption of two-dimensional turbulent motion, represented the exact conditions. About eighteen months ago Schlichting had worked out the results of Prandtl's theory, to give the distribution of mean velocity in a wake, and he (Professor Taylor) had thought it worth while to measure the distribution and temperature which his own theory would give; to his great surprise he had obtained a result which was predicted by his theory. Therefore, although in Mr. Fage's measurements and in his own previous measurements in the atmosphere there was the tendency to three-dimensional motion, he supposed that in the particular experiments he was referring to the turbulent motion was limited to two-dimensions. Something still remained to be done in that respect. The experiments described by Mr. Fage on page 591 of the paper seemed to indicate that the motion was three-dimensional behind a single object, placed in a stream, and that, of course, disagreed with the assumption made in that theory. Mr. Fage's values of Reynolds number, and so on, were not quite the same as the values used in the heat experiments with the cylinder. Therefore, Professor Taylor suggested that a measurement of turbulent components behind the actual object which was used in the heat experiments ought to be made, with a view to finding whether there was any difference between that and Mr. Fage's results. The alternative, of course, was that the kind of motions which produced the distribution of the mean motion, which were considered both in Prandtl's and his own theories were not exactly the same turbulent motions as those measured by Mr. Fage. For instance, in the second part of Fig. 12 the values of u_1/U, w_1/U, and so on, were very high—up to 0.4 in that experiment. Fig. 11 showed the difference between the mean velocity in the middle of the wake and the mean velocity outside it. The maximum was only .15 in one case and .07 in the other. That was very much less than the 0.4, which occurred in Fig. 12, and it must be remembered that the variations in velocity which occurred, according to Prandtl's theory, were necessarily less than the difference between the velocity at the centre of the wake and the velocity outside the wake. Therefore, the maximum difference in velocity which one ought to get in the wake according to Prandtl's theory, or his own theory, was very much less than 0.159—at least in the particular cases for which Mr. Fage had carried out the experiments. So that there was some hiatus or gap there which needed filling up.

Finally, Professor Taylor said he believed the new method had very great possibilities; he hoped Mr. Fage would go on with the work, and combine his methods with other methods, such as hot wire measurements, and so forth.

Dr. MACCOLL (*Associate Fellow*): He would like to comment on the fact that Mr. Fage and Dr. Townend had used a channel of square cross-section. In some previous work on fully developed turbulent flow, there had been evidence of secondary motions being set up when the channels were of rectangular or triangular section. By these secondary motions the fluid in the centre of the channel was carried towards the corners and returned inwards again after having moved along the sides. These motions would give steady values to the velocity components v and w in addition to the fluctuating values due to turbulence. He asked, therefore, if Mr. Fage had any evidence in his investigations of the presence of secondary flows.

He considered that this type of investigation should be carried further in some of our Universities as the necessary apparatus was fairly simple and inexpensive. In collaboration with Mr. Fage, certain problems might be given to research students—problems such as those of the flow in diverging, converging and circular channels. Mr. Fage's work marked a distinct step forward towards a clearer understanding of turbulent flow and he hoped that the work would be continued.

Dr. PIERCY (*Fellow*): Mr. Fage and Dr. Townend had taken a valuable step forward in developing the use of the ultra microscope in studying turbulence, and he congratulated them upon the results already achieved. So far the outstanding result had been to demonstrate beyond quibble the importance of the transverse pressure variation. One imagined immediately that it would be interesting to have experiments made on the effect on the critical Reynolds number of transverse curvature of a surface over which fluid was flowing. He rather fancied, however, that any success here, and in some other cases, would depend upon introducing graded finite disturbances. Probably this step was necessary in theory as well as in experiment. Nearly ten years ago Professor Taylor had given them methods of examining stability which had proved remarkably successful in his hands and also in at least one other case of which they all knew. Without doubt definite results were to come in others. But a number of cases had been worked at in which the method seemingly failed to give critical Reynolds numbers according with engineering experience. Such cases tended to show stability for all Reynolds numbers, and further experiment seemed to relate the result to size of disturbance for, on greatly diminishing this, critical Reynolds numbers which had appeared quite definitely greatly increased.

The method of small oscillations had proved remarkably successful in another phase of aeronautics, *i.e.*, the stability of aircraft motion. He suggested that what they regarded as large oscillations in aircraft motion would appear small if compared with those to which elements of a fluid in motion were subjected under engineering conditions. It seemed desirable for further progress on the theoretical side, in relation to engineering conditions, to have a development of method which would enable them to take account of finite oscillations and to examine stability on that basis. If that step were possible, he believed that on the experimental side cases could be isolated where the steady flow would be definitely separated from developed turbulence by an intermediate regime of unsteady, but not incoherent, flow, of such type that experiment might help with the calculations.

Mr. RELF (*Fellow*): He had had the opportunity of appreciating some of the difficulties which Mr. Fage had had to contend with at the N.P.L., and he congratulated him upon the beautiful piece of experimentation he had described on the use of the ultra-microscope. The really important thing that Mr. Fage had done was to direct attention to the three-dimensional nature of developed turbulence, though he was afraid that that would give the mathematicians a headache. He did not know whether it was right to say that no mathematical process had shown them the beginning of turbulence, because one had hitherto always worked on two dimensions, the equations in three dimensions having so far proved intractable. If this were so, it meant that there was no hope of progress unless they could deal with the equations in three dimensions. He did not imagine that this would be done in the immediate future, but he hoped to live long enough to see some sort of solution of that kind.

It was to be hoped that it would prove possible to continue the work at the laboratory, because, having discovered a method which was new, the obvious thing to do was to apply it to as many cases as possible, in order to find out whether any new facts were forthcoming which would help in the general investigation of the subject of fluid motion.

Dr. WINNY: With regard to the author's statement that the only direct prediction of the birth of eddying motion from the equations of motion was due to G. I. Taylor, perhaps in that connection one might recall the work of Dr. Jefferies, who had predicted the birth of eddies in a fluid contained between two horizontal flat plates, the bottom one being kept at a higher temperature than the top. In that case there had been predicted both the form of the eddies and the temperature difference at which the eddies would be produced, and the

mathematical results have been found to agree with the experimental results. He understood that this work had been correlated with Professor Taylor's work, the type of disturbance being shown to be the same as that worked out previously by Professor Taylor.

It was stated by Mr. Fage, in his equation (in the section of the paper dealing with the cause of eddies)—which gave a view of the physical significance of Reynolds number when turbulence occurs—that the viscous force was proportional to $\mu v/l$. Dr. Winny did not understand this statement, if v were regarded as being the velocity of the fluid and l were the dimensional length, since, for example, the viscous force per unit area on a flat plate moving tangentially is known to vary approximately as $(\mu v/l)\sqrt{(vl/v)}$.

With regard to the statement (in connection with the turbulent velocities in a pipe) that the disturbed velocities could be deduced on mathematical grounds by assuming a pressure gradient transverse to the flow, Dr. Winny asked whether that analysis gave any indication of the cause of the transverse pressures, or whether the transverse pressures were assumed to be impressed externally on the fluid considered, and the experimental disturbance of the velocity thus reproduced.

Professor G. I. TAYLOR: He would like to comment upon Mr. Relf's advice to mathematicians to pull up their socks and get to work on three-dimensional motion. The solution given by Mr. Fage, of course, entirely depended on the fact that it was three-dimensional.

The CHAIRMAN: The last remark made by Professor Taylor, combined with Mr. Relf's remarks, would rather suggest that they had no turbulence problems in fluid motion which were not three-dimensional. Perhaps, however, that was a little pessimistic. In the work by Jones at Cambridge the development of circulation around an aerofoil had been followed, and everything had been assumed to be two-dimensional, and it was very good. Other work at the Imperial College suggested that two-dimensional problems might be sufficient to indicate practical problems for the mathematician, and he believed that to some extent even Mr. Fage's results indicated three-dimensional motion behind a prism only at positions a long way behind it. His impression was that the motion in the neighbourhood of a cylinder itself was closely streamline, and even though eddying motion ultimately developed down stream, one could still have substantial streamline motion, and this could be investigated as such, so avoiding the complexity attaching to three dimensions.

Another point was, although one had to take fluctuations of the velocity in both directions at right angles to the main flow, the amount of this fluctuation was not a very big proportion of the axial velocity. If velocities were combined by the ordinary method of the square root of the sum of the squares, that possibly accounted for the fact that approximations in one-dimension or two-dimensions were not so bad. The main interest of the paper, however, and the matter on which congratulations were so well deserved, was the fact that for the first time in the history of aeronautics, or the study of fluid motion, they were able to observe what happened very close to a solid surface. The author had mentioned Dr. Stanton's pitot tube. A very small pitot tube did not give a sensible reading. Both Professor Taylor and Dr. Stanton had shown that if the tube were made smaller and smaller, and was nearer and nearer to the surface over which it was intended to measure velocity, it gave results which became more and more inaccurate. On the other hand, Mr. Fage worked at distances from the surface less than 1/10,000th of an inch with considerable certainty.

The Chairman joined with other speakers in expressing the hope that the work described in the paper would be continued. He did not see where it would lead, nor did he see any theory which took it into account at the moment, though the correlation between the changes of velocity near the surface and Professor

Taylor's mathematical theory seemed to indicate a starting point. In spite of that, he considered that the observations should be continued and an attempt made to deduce a theory, at any rate for the boundary layer itself. As to the suggestion that some of the work could be carried out conveniently at some of the Universities, the Chairman pointed out that this must depend on the existence of suitable students and as for others the present is a rather difficult time.

Prof. L. PRANDTL (*communicated*): It is a pleasure to have the opportunity of sending a written contribution to the discussion of Mr. Fage's paper. He had always kept in touch with the published work of the Aerodynamics Department of the N.P.L. and had been particularly interested in the investigations, made by Mr. Fage and his colleagues, of the behaviour of a fluid in turbulent motion, so that most of the papers referred to by Mr. Fage were familiar to the writer. Next to the original and instructive studies of flow with the aid of an altra-microscope, he attached the greatest importance to the discussion in §§31, 32, of the relationship between the distributions of temperature and velocity in the wake of a heated body, since these experiments afford a means of examining the relative merits of Professor Taylor's theory of turbulent flow and his own. There is no doubt that Mr. Fage's observations are in favour of Professor Taylor's theory for the case of the flow in the wake of a body. In Göttingen they had recently made investigations with the airstream from a nozzle which mixes with the surrounding stationary air of a different temperature. In this case also they found a difference between the temperature distribution and that of the velocity, which is in agreement with Professor Taylor's theory.

In contradiction to the above results, however, special attention must be paid to the fact mentioned also by Professor Taylor that, for the case of the flow with high velocity over a heated surface, the distributions of velocity and temperature are almost identical. Experiments of this type have been made by Éliás* in Aachen. For the flow over a rigid boundary, therefore, the experimental results are in favour of my theory. It is fortunate that it is so, since Professor Taylor's formula completely fails to interpret this type of flow, whereas the writer's theory provides a particularly simple solution.

For the flow along a smooth straight wall, the following formula for the velocity distribution, as a function of the distance y from the wall, has been derived from the experimental results:—

$$u = 2.5\sqrt{(\tau_0/\rho)}\,\{\log_e (y/\nu)\sqrt{(\tau_0/\rho)} + 2.2\} \quad . \quad . \quad . \quad (1)$$

where ρ is the density, ν the kinematic viscosity and τ_0 the tangential stress at the wall. Using the writer's formula for the apparent tangential stress τ of the turbulent motion,

$$\tau = \rho l^2 (du/dy)^2,$$

and the above value of u, there is obtained the simple relation $l = 0.4\,y$, when $\tau = \tau_0 =$ constant, as for example in the Couette flow. This is a reasonable result also from the standpoint of dimensional analysis, because y is the only length available in this problem. For the same case, Professor Taylor's formula would give

$$d\tau/dy = \rho l^2 (du/dy)(d^2u/dy^2) = 0,$$

and therefore $l = 0$ or $d^2u/dy^2 = 0$. The solution $l = 0$ is not consistent with the existence of the transport of momentum and heat. If, on the other hand, $l \neq 0$, $d^2u/dy^2 = 0$ and therefore $u = a + by$, where a and b have arbitrary values which have no connection with τ_0. In addition to this theoretical difficulty a linear velocity distribution is never observed in turbulent flow at a wall. Prof. Taylor assured him recently in a letter, that he himself would not think that the

* F. Éliás, Der Wärmeübergang von einer geheizten Platte an strömende Luft. Abhandlungen des Aerodynamischen Instituts Aachen, Vol. 9 (1930), p. 10.

formula referred to here as " Taylor's formula " should be applicable to the flow near a wall, because according to Mr. Fage's observations the flow is found to be essentially three-dimensional, while Prof. Taylor's theory assumes two-dimensional disturbances.

With reference to the relation between Prof. Taylor's theory and his own he might add, that the Taylor theory, which is older than his, was first brought to his notice on the occasion of a visit to Professor Taylor in May, 1927. A few weeks ago he wrote to him his doubts with regard to the application of this theory to the flow along a wall and, at the same time, he showed that his formula holds, when the mixing motion is caused by vortices with their axes parallel to the direction of flow. For example, a vortex pair of this type, transfers fluid particles from the boundary to the interior of the fluid and vice-versa, unaffected by pressure differences. Prof. Taylor has shown in his paper, referred to by Mr. Fage, that, when vortices are established with their axes parallel to the direction of flow, the writer's formula is valid and that the rate of interchange of momentum is therefore equal to that of heat.

The following picture gives a further development of the motion caused by a vortex pair as described above. The band of particles transferred to and now surrounded by fluid moving with a different velocity is unstable and breaks up into separate vortex formations, which, he thought, are extended more and more owing to the velocity differences in the main stream, as the flow continues. There again vortices are formed with their axes approximately parallel to the direction of flow, and these transfer again other fluid particles into regions moving with a different velocity. The greatest extension of the vortex structure naturally occurs where du/dy is large and there is no tendency to extend them where $du/dy = 0$. In this way it is possible to explain the fact, established by Mr. Fage, that the velocity component w_1 is as large as u_1 and that both increase towards the wall.

If in accordance with what has been said above, the instability of the flow along a wall is called " secondary instability " (instability caused only by displacements produced by a disturbance), then on the other hand the instability in the wake of a body, and in other types of flow with free surfaces of separation is a " primary instability." In the latter, each surface of separation is unstable and breaks down forming a series of large vortices with their axes normal to the wind direction and parallel to the surfaces of constant mean velocity, as in Professor Taylor's assumption, so that there is no extension in the direction of the main stream. It is thus easy to understand why the turbulence in the frictional layer along a wall does not obey the same law as that in the boundary of a free jet or in the wake of a body.

Dr. E. G. Richardson (*communicated*): He had read Mr. Fage's paper with great interest, in particular the conclusion that steep pressure gradients at the solid boundary lead to fluctuations in both magnitude and direction of velocity. Dr. Piercy and he were led to similar conclusions in their investigation of the velocity fluctuation near the surface of a model in a wind channel, where surprisingly large fluctuations were found close to the front stagnation point. These latter measurements were made with a hot wire coupled to a string galvanometer, in the use of which it is necessary to apply corrections both for the nearness of the solid surface and also for the mean velocity about which the fluctuations take place.

He was at University College while the ultra-microscopic measurements of Nisi and Porter were being made, and he remembered that they had considerable trouble with the heat from the arc upsetting the flow. They were using air and smoke particles. He would like to ask Mr. Fage whether he experienced trouble with convection currents, and if so, what precautions he took to overcome it. Also had he considered the feasibility of replacing the microscope with a camera

while retaining the moving objective? This would enable the resulting plates to be examined at leisure, and while being more tedious, would avoid having to rely on visual judgment of the spots and streaks.

Reply to Discussion

Mr. Fage said he wished to express his great appreciation of the generous manner in which the paper had been received. He thought the appreciation shown by the speakers should be extended to Dr. Townend, who had collaborated in the ultra-microscopic examination of turbulent flow in a pipe. He also wished to thank Professor Bairstow for taking the chair.

He felt he was greatly honoured that Professor Taylor had made a special journey from Cambridge to take part in the discussion, for Professor Taylor was a great authority on turbulence problems, and recognised as such not only in this country, but throughout the scientific world. Professor Taylor had made the interesting suggestion that measurements of the turbulence ratios u_1/U, v_1/U and w_1/U should be made in the wake behind the cylinder used in the heat experiments described in §31, to see whether they would be smaller than the measurements made behind the prism of §33, at a lower Reynolds number. This experiment was worth doing. The measurements with the prism were made to determine whether the eddying motion behind a long cylindrical body was three-dimensional. The results given in Fig. 12 showed that the disturbances were three-dimensional, and it was to be expected that they would remain so at a higher Reynolds number. The values of u_1/U, v_1/U and w_1/U fall with the distance downstream, and a distance could be selected where they would have the same magnitudes as those at the section behind the circular cylinder where the measurements of velocity and temperature were made. The experiments on the prism did suggest that the completely developed eddying motion behind the cylinder would be three-dimensional.

Dr. Maccoll raised the question whether secondary motions were observed in the square pipe. Observations of mean direction taken during the experiments indicated the existence of secondary motions, but the angular deviations of the mean flow from the axial direction were small, and generally not appreciably greater than probable errors in the measurements of Θ_{xy} and Θ_{xz}. Work on one of the problems suggested by Dr. Maccoll, namely, the effect of converging flow on turbulence, had already been undertaken, and some interesting results had been obtained.

Everyone would agree with the remark made by Dr. Piercy, that valuable progress would be made if we had a method of examining stability which took account of finite oscillations. Such a theory would have a useful application not only in fluid motion, but in the stability of aeroplane motion.

Mr. Relf had remarked that the fact that all diffused motion was three-dimensional presented additional difficulties to the mathematician. It is comforting to know that although this may be so, knowledge obtained from observation of the motion of a fluid under certain boundary conditions, would eventually help the mathematician to obtain an analytical solution for the motion.

He was indebted to Dr. Winny for the reference to the work of Dr. Jefferies. The explanation of the cause of eddies given in §6 would not bear too close a scrutiny. Obviously, it was difficult to explain exactly how eddies were caused, and possibly the only merit of the view given was its simplicity. With reference to the last question raised by Dr. Winny, the transverse pressures were associated with the velocity disturbances, and these were calculated (see Ref. 5).

The remarks of Professor Bairstow were very interesting. The disturbances associated with the vortices in the Kármán street behind a long bluff obstacle tended to be greater in planes at right angles to the axis of the body, and even although the disturbances in the dead air region were three-dimensional, it would

seem justifiable to assume, as mathematicians had done, that the flow in the near neighbourhood of a cylinder could be treated as a two-dimensional problem.

He was greatly indebted to Professor Prandtl for the valuable and helpful contribution which he had made to the discussion. There appeared to be little doubt, as the observations given in the paper had shown, that the velocity disturbances at the surface of a body differed from those in the eddying wake behind a long cylindrical body, and as Professor Prandtl had shown, it would seem that there were good reasons why his theory should hold more closely in the one case and Professor Taylor's theory in the other. It was here of interest to mention that in one of our experiments, the flow in a circular pipe was illuminated by an axial beam of light, and the rotation of particles about the axial direction, of which Professor Prandtl speaks, was then clearly visible.

The measurements to which Dr. Richardson referred were made in the wakes behind very small obstacles mounted in a slowly-moving air stream, and unless precautions were taken, convection currents arising from the heat of the arc would modify the flow. No trouble from convection currents was experienced in the experiments described in the paper, for the fluid used was water, and the speeds were too great to allow the water to be heated to any measurable extent. Photographic records of the flow would certainly allow the motion to be examined at leisure, but the accuracy of observation would not be increased by this method. The great advantage of the method of operation described in the paper was that observation could be prolonged until satisfaction was obtained.

At the conclusion of the discussion a hearty vote of thanks was accorded Mr. Fage for his paper.

The 559th Lecture read before the Royal Aeronautical Society since its foundation January 12th, 1866.

PROCEEDINGS

THIRD MEETING, SECOND HALF, 68TH SESSION

The Third Meeting of the second half of the 68th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, February 2nd, 1933, when a paper on " The Amsterdam-Batavia Weekly Service " was presented by Mr. A. Plesman, Managing Director of the Royal Dutch Air Lines (K.L.M.). In the chair, Mr. C. R. Fairey, President.

The PRESIDENT: He extended a hearty welcome to the Society's distinguished guest, who was to tell the story of the solid achievement of the K.L.M. in the organisation of the air service from Amsterdam to Batavia. It was very pleasing to hear a story of successful pioneering which had resulted in a real and genuine advance in aerial transport. There was no one better qualified than Mr. Plesman, the Managing Director of the K.L.M., to tell the story of the difficulties and the successes, since he was the person finally responsible for the achievement. He was also a Director of the Royal Netherlands Indian Airways.

THE AMSTERDAM-BATAVIA WEEKLY SERVICE

BY

A. PLESMAN

Managing Director of the Royal Dutch Air Lines (K.L.M.)

A regular air service between Amsterdam and Batavia has now been in existence for more than two years, a fact which to-day is generally known. The great and mutual interests which bind Netherland with its colonies—interests of a cultural, commercial and also of a governmental nature—have always placed in the foreground the necessity of bridging over as rapidly as possible the enormous distance separating both territories. Two shipping companies, the Netherland Royal Mail Lines and the Rotterdam Lloyd, provided for transport by sea, and spared no labour, expense or trouble to render this means of communication as rapid, regular and comfortable as possible. Telegraphy naturally also made a rapid exchange of thought possible, and this telegraphy was still further improved during the war through the institution of a wireless telegraphic service; whilst, since 1930, wireless telephonic communication is possible from the Netherlands with the principal towns of Java and North Sumatra. It is understandable, therefore, that in the same way the idea developed of establishing an air service between Amsterdam and Batavia. This idea was already nascent in the mind of the Board of Directors of the K.L.M. in the first years of the existence of the company. Many members of this Board, indeed, were leaders of great enterprises established in Netherlands India, with headquarters in Holland. Once the idea was regarded as possible it was never relinquished, but steadily materialised. In considering the genesis of the air service Amsterdam-Batavia, one ground for satisfaction is the fact that, notwithstanding the inevitable set-backs, the development both of the operation and the transport itself has been normal and shows a satisfactory increase.

Before a beginning was made with regular operation, various test-flights were carried out. On October 1, 1924, the K.L.M. pilot Van der Hoop started from Amsterdam, supported in his enterprise by the Committee " Flight Holland-India " and by the Netherlands Postal Department. It was the successful flight of this pioneer, carried out in extremely difficult circumstances, and also his most convincingly-written book, which opened the eyes of the public in Holland to the possibilities of an air service to India. Three years, however, were to pass before the next attempt was made—an attempt which was due to the fact that the American Mr. Van Lear Black, who had already made several special flights with the K.L.M., expressed the wish to undertake a flight to Netherlands India. Notwithstanding the scanty preparations and the fact that neither the engine nor the machine were constructed to fly through the monsoon rains which swept a considerable section of the route, whilst further there was even no opportunity along the route of filling up with fuel of the desired composition, this flight, thanks to the excellent abilities of the crew (Messrs. Geysendorffer, Scholte and Weber), was successfully carried out. The flight out was performed in 13 days, and the return flight in 14. Shortly afterwards a new flight was carried out under command of Koppen, with the support of the above-mentioned Committee, the first flight with a triple-engined Fokker machine, the " Post Dove." This flight was performed in the excellent time of nine days out and ten days home. In the meantime, the Royal Netherlands Indian Airways had been founded in India, and an opportunity was offered in 1928 of flying out to India the machines destined for that company.

On the occasion of these first test-flights, very praiseworthy support and co-operation were given by the Netherlands Postal Department. The Management of this institution did not adopt the standpoint that an air service between Amsterdam and Batavia should first have materialised before it was granted facilities for carrying mail, but realised from the very beginning that this air service, if it was to be established, should be able to reckon on the greatest possible co-operation of the Postal Department. In the most broad-minded spirit, therefore, even the first test-flights in 1928, and those which followed in 1929, were granted every facility for the carriage of mail, and its transport was adequately paid for. That a regular air service has been established is due, therefore, in the first place, to the support and the far-seeing spirit of the Dutch Postmaster-General.

When this method of transport was in course of preparation, the K.L.M. had no lack of good counsellors. There were those who pointed out that the route Amsterdam-Batavia was for a considerable part a sea route, and ought, thus, to be run with seaplanes. There were others who argued that the route ought to be subdivided into various parts and flown on the estafette system. There are many to-day who criticise the fact that the cargo carried is miscellaneous instead of being restricted to mail.

These are a few of the problems. When one takes in hand, however, the operation of an air service like that of Amsterdam-Batavia, the following problems present themselves in mutual relation:—

The choice of material.
The choice of route.
The choice of cargo.
Personnel.
The method of operation (estafette system, through traffic).

With those problems in view, we have arrived at the present form of exploitation—a form which presents various sides which require further elucidation.

Choice of Material

In the first place there was the problem: land or seaplane. This question was decided in favour of the former, because the view was held that a real seaplane, able to resist a heavy sea, had yet to be constructed, whilst the seaplane as regards acquisition and upkeep is far from economic in operation. Further, the adoption of a sea route would have necessitated either a considerable detour or long flights with seaplanes over the mainland. Another solution, of course, would have been to employ various types of machines, *i.e.*, both sea and land machines, or else amphibian craft. For various reasons, however, which will be referred to later, the K.L.M. does not favour operating the service with various types of aircraft. Moreover, the shortest route leads for the most part over land and for that reason the choice of the aeroplane was from the very beginning regarded as self-evident. A first requirement for the machines on the

Some of the geographical, meteorological and political hindrances on the AMSTERDAM-BATAVIA air route

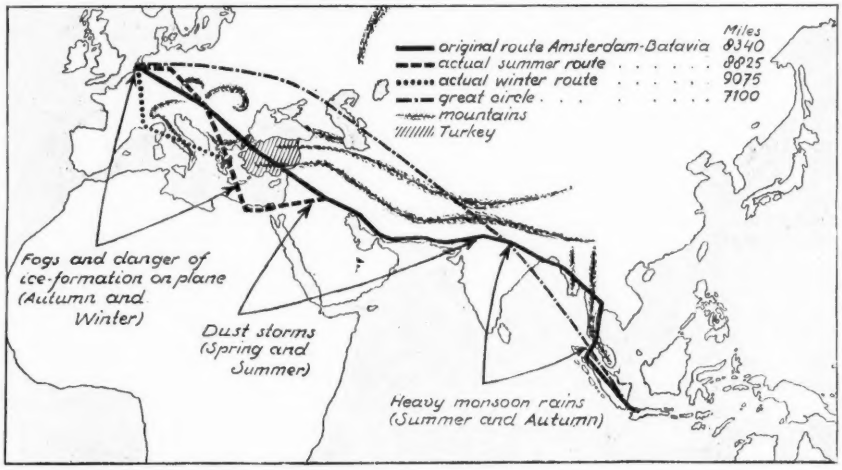


FIG. 1.

Indian route is that a possible defect in one of the engines need not directly necessitate a forced landing. This means that a multi-engined machine shall be able to fly at a fairly safe altitude and remain under control, even when one of the engines has stopped. A machine equipped with three engines has up to the present been the choice of the K.L.M. and the results have been excellent. It is very improbable that a second engine would stop at the same time. Flying with two engines and with a machine fully loaded must be possible under the most unfavourable circumstances. The machines successively placed on the Indian route by the K.L.M. answer these requirements, and where experience has proved that during 20,000 hours of operation, no forced landing outside an aerodrome owing to engine trouble took place, one can risk flying with an aeroplane across the Mediterranean or over the jungles of Burmah and Sumatra. Later, we shall give a further description of the material now in use.

Choice of Route

Once the decision was taken to operate the service with aeroplanes, a number of other—often conflicting—considerations presented themselves. As starting point of these considerations, the shortest line of communication between Amsterdam and Batavia—the great circle—had only value as a standard of comparison. This shortest route is 11,360 km. (7,100 miles) long, and runs from Amsterdam, via Berlin, over Astrakan, through Turkestan, transversely over the Himalayas, skirts Delhi and the Adamen Islands, passes almost over Medan, to Batavia.

Many reasons make deviation from this shortest route desirable, even if it is not impossible, in theory, to follow it. The chief objections to do so are the following:—

The nature of the country, in a vertical sense;
Weather conditions;
Considerations of traffic economy;
Political difficulties;

whilst apart from all this, the choice of route is finally determined by a fifth factor: The *ground organisation* already existing or practically possible.

With regard to the vertical nature of the country flown over, it may be said, generally speaking, that flying over low areas (plains or sea) guarantees greater safety and regularity than flying over hilly or mountainous country. Although technical difficulties no longer prevent aeroplanes from reaching even a very great height (the altitude record is actually about 40,000ft.), flying over mountains is extremely undesirable for an air traffic company. In the first place the loading capacity is very unfavourably influenced when flying at great heights, especially when one must adhere to the principle that a triple-engined machine may not be forced to land by the stopping of one engine. For these reasons, mountainous regions like the Himalayas or the Pamir plateau still constitute insuperable difficulties for air traffic. Perhaps the stratosphere aeroplane will eliminate this impediment later on. Further, low hanging clouds in mountainous or hilly country will render navigation more onerous or flying more difficult owing to ice forming on the aeroplane, than when flying over low country.

The connection between weather conditions and choice of route can best be explained by an example. At the end of 1930, the European section of the Indian route ran from Amsterdam, via Budapest to Athens. During the winter of 1930-31, the regularity attained on this section proved insufficient. As matters stand at present in the technique of aviation, Central Europe and the Balkans are less suitable for air traffic in the winter months owing to snowfall, the chance of formation of ice on the machine, low-lying clouds and bad visibility. As a result of the experience gained the following system was adopted during the winter 1931-32:—On the basis of the forecast of the Royal Dutch Meteorological Institute, a decision was taken for each flight separately whether the machine would proceed via Central Europe or via Marseilles and Rome to Athens. For the outward journey this was decided in concert with the pilot at Amsterdam. For the journey home, the pilot received telegraphic advice at Athens. The route via Marseilles and Rome was prepared in good time, whilst along both stages the arrangements made were so that a few telegrams were sufficient to inform all concerned which way the machine would come.

Although the southerly route was about 300 miles longer, the experience gained during the winter of 1931-32 was so positive as regards safety and regularity, that for the winter and spring period of 1932-33, this winter route was adopted permanently. At present, from November 1st till the end of April, the flights take place via Marseilles and Rome; in the other six months via Budapest.

Considering the economic importance of the choice of route, then, it is clear that it is more desirable to have intermediate landings at great commercial and traffic centres than at stopping places arbitrarily chosen. As long as the freight

carried does not fill the machine from starting point to final destination, it is of importance to increase the receipts by the transport of mail, passengers and goods. Moreover, in this way, one renders the countries concerned the service of linking them up in world air traffic and achieves the result that the interests of the countries over which the air route passes coincide with those of the transport company. In this respect, landing places like Halle, Leipzig, Budapest (in winter Marseilles and Rome), Athens, Cairo, Baghdad, Karachi, Calcutta, Rangoon and Bangkok, all of which are touched by the air line Amsterdam-Batavia, are very favourable. It is all the more remarkable that few of these countries show no desire to make use of the enormous advantages in the sphere of rapid communication which the K.L.M. line offers. At Rome passengers are not permitted to land or embark, whilst it is also forbidden to load or unload goods. British India also, only wishes to send mail on a very restricted scale with K.L.M. machines, in spite of the fact that the business world in that country, once it had learned thoroughly the advantages of the communication afforded by the K.L.M., through the mail *received*, has called for it for years.

And here we approach one of the most remarkable obstacles threatening international air traffic—the political factor. This political factor seems to be the worst enemy of air traffic. One frequently hears it asserted that air traffic, knowing no frontiers, will contribute to effect closer co-operation and a better mutual appreciation among the nations. Few suspect, however, to what an extent air communications are still all too frequently a source of political obstruction and wrangling. Let us hope that the political factor in air traffic is on its last legs but that it does not kick out too vigorously in its death struggle.

During the early development of the air communication between Holland and its colonies in the East, everyone feared the technical difficulties, and although the final goal has not yet been reached, it appeared that technique and science—to a greater extent than was expected—were able satisfactorily to answer all requirements. But the difficulties in the political sphere, the source of so much unnecessary waste of energy, were greater than the technical difficulties will ever prove to be. We will not go into details, but restrict ourselves to one example, but one which throws everything into the shade as an example of short-sighted air traffic policy—that of Turkey. This country seems to see its national salvation in hermetically closing itself to all modern means of communication. Unfortunately this country lies on the route which the K.L.M. had originally chosen as the most suitable—in other words, the shortest. Without any reason being given, Turkey refused its consent to the K.L.M. flying over its territory. And it is not only the Dutch air traffic which found itself here up against a stone wall. Nevertheless, it would seem that a change in the Turkish attitude is imminent.

To what circuitous routes one is compelled, owing to various considerations, is seen from the following comparison of distances between Amsterdam and Baghdad:—

Amsterdam - Baghdad, direct	3,775 km. (2,360 miles)
Amsterdam - Budapest - Stamboul - Aleppo - Baghdad	4,030 km. (2,520 miles)
Amsterdam - Budapest - Athens - Cairo - Baghdad	4,865 km. (3,040 miles)
Amsterdam - Marseilles - Rome - Athens - Cairo - Baghdad	5,350 km. (3,345 miles)

However, as already stated, after all considerations of desirability, the *ground organisation* existing at a certain moment finally determines the route; in other words, opportunity to land, to refuel, and to pass the night. With every machine, the connection between its radius of action and the loading capacity is very simple, viz., a connection controlled by the maximum admissible weight of the machine, which, in its turn, is determined by the constructional strength

and its take-off qualities and rate of climb. The transport of pay load being the object, the final choice of the route—taking the various other considerations mentioned into account—is dependent on the existence of available landing grounds, regularly distributed. The weakest link determines the strength of a chain, and so the greatest distance between the two successive aerodromes determines the maximum profitable load which, from one end to the other, can be carried by each machine from Amsterdam to Batavia. In this way the following route was settled upon:—From the beginning of May till the end of October: Amsterdam - Halle - Leipzig - Budapest - Athens - Mersa Matruh - Cairo - Gaza - Baghdad - Bushire - Jask - Karachi - Jodhpur - Allahabad - Calcutta - Akyab - Rangoon-Bangkok-Alor Star-Medan-Palembang-Batavia, the total distance being 14,185 km. (8,825 miles), while from November till the end of April the first part of the route is changed via Marseilles, Rome and Athens, which is some 500 km. (300 miles) longer.

Relay System

A route like that indicated above may be flown in various ways. A certain stage of the route may be assigned to a certain group of pilots, on which stage they might specialise. The route Amsterdam-Batavia could be divided into definite sections, such as Amsterdam-Baghdad, Baghdad-Calcutta, Calcutta-Batavia. At present the K.L.M. is the only company operating a long air line that occupies the standpoint of regarding the aeroplane as a ship which makes the journey out and home with the same crew. This system has the following advantages—one need not station material or personnel *en route*, which in the first place means a very great economy. It is self-evident that the stationing of aeroplanes along the route—machines which require upkeep, burdened with landing and housing fees, and where the proportion between rest hours and flying hours would be unfavourable—is extraordinarily expensive. The same applies to the stationing of personnel. But the final and chief argument against stationing machines along the route is that it would mean a considerable increase of the fleet. The weekly service Amsterdam-Batavia can be operated with six machines. Further, there is the consideration that each machine arriving at Bandoeng forms a reserve during one week. Against the presumed advantage that the specialising of pilots on a certain stage of the route ensures greater safety and regularity, may be placed the disadvantages resulting from the stationing of personnel—more especially when these stations are situated in unhealthy regions. A permanent crew flying the machines out and home again has several advantages. In the first place, the crew feels itself more responsible for the journey *as a whole* than one which only serves a section. In the second place, the crew, after nine or ten days, can take a rest in the agreeable climate of Bandoeng and be back in Holland again in a month in their own home and with their own family. The rapid passage through different countries and climates has, as we shall show later, no unfavourable effects. The same crew serving on the journey out and home means a better control over the whole of the operations—technical, commercial, and also medical. Immediately on arrival at Bandoeng the crew sends a report by wireless telephony over the principal points of the journey. These points are: Health, engines, instruments, aeroplane, wireless, agents, petrol and oil, landing grounds, weather conditions, the mail, passengers and goods loaded, deviations from the itinerary, number of flying hours, petrol consumption, oil consumption, average number of revolutions, general remarks, bookings for the return flight, etc. On the return to Amsterdam a meeting is held, in which the navigation and log-books which are posted up *en route* are carefully controlled—in which manner a detailed knowledge of the route is acquired in a short time.

Instead, then, of stationing personnel and material along the route, the storage of reserve parts for engines and machines sufficed from the very beginning,

which reserve parts, since the F XII and the F XVIII machines were commissioned for the service, have been restricted to a minimum. Nowhere between Amsterdam and Batavia has the K.L.M. its own personnel.

Each crew makes four flights out and back annually. The outward journey lasts 9 to 10 days, the period of rest at Bandoeng 13 or 12 days, the journey home again 9 to 10 days, after which follows a week's holiday. Further, the crew remains seven weeks on the European lines of the K.L.M. Between each departure for Batavia, thus, there lie 13 weeks, and as four weeks multiplied by thirteen make a year, there are at least 13 crews needed, each of which performs four journeys. It must be noted that this system is only possible owing to the fact that the K.L.M. has an important European service beside the Amsterdam-Batavia line.

The Choice of Etappes

The principal factor which determines the division in daily stages is the rule set by the company that the start must be made a short time before sunrise and the last landing made at least an hour before sunset, which means, practically speaking, that one only flies by daylight. The considerations which led to this decision were, among others, the rather slight experience of night flying possessed by the K.L.M., the fact that the ground organisation on the Indian route is not yet prepared for night flying, and finally, the rapidly increasing fatigue, if *one* crew, in addition to working the whole day, should be called upon to continue working during a part of the night.

This flying system has led to a division of the approximately 14,500 km. (9,000 miles) long route into nine daily stages in summer and ten in winter.

One flies eight to nine hours a day with a speed of 185 to 195 km. per hour (115 to 125 miles per hour).

It is clear that as long as this system is maintained (one machine with *one* crew for the whole journey and flying for the most part in daylight), the journey on a chosen route can only be shortened by an increase in the speed of the machines, and it is just this increase in speed which the K.L.M. has always had in view (in 1929, the F VIIb machines with a cruising speed of 165 km. per hour (100 miles per hour); in 1931, the F XII machines with 185 km. per hour (115 miles per hour); and in 1932, the F XVIII machines which attained a speed of 195 km. per hour (122 miles per hour)).

But even if the greater speed of a new machine is insufficient to shorten the journey immediately by one day, it greatly increases the regularity of the service, not only by increasing the available margin of daylight, but also by relatively reducing the effect of head winds.

A third reason for greater regularity as a result of a greater speed is the larger speed surplus (the difference between maximum speed and cruising speed) which the more rapid machine possesses and which can be taken advantage of in special circumstances.

One of the bases on which the flying scheme has rested, and indeed still rests, is the available daylight. The great differences in this respect over the part of the route between Amsterdam and Cairo during the favourable summer period and in the middle of the winter have resulted, together with the somewhat longer winter route, in two time tables—in summer nine days and in winter ten.

In considering the question of available daylight, the following facts must also be taken into account. The difference in time between Amsterdam and Batavia, as a result of the difference in longitude, amounts to about seven hours. In other words, flying from west to east, seven hours of daylight is lost on the whole journey, whilst in the reverse direction the same number of hours is won, which results in a difference of no less than 14 hours of available daylight between the journey out and the journey home. It is clear that this difference between the outward journey and the journey back will play a greater *rôle* according to

the number of travelling days being reduced. With the journey lasting ten days, an average of only 1 hour and 24 minutes less per day can be flown on the outward journey than on the journey home, whilst the difference in the case of a journey of five days amounts to double. A speeding-up of the scheduled time, therefore, must finally lead to a different time table in both directions, that is to say, that in the case of a very rapid service, the journey out will last one day longer than the return journey.

It is the intention to perform, in the summer of 1933, the journey in eight days and in the autumn and winter in nine days.

With the above-mentioned system, the number of hours flown in darkness, that is, at the beginning of each day's stage, amounts to no more than one to two hours—three is an exception. In the future, however, with an increase in the number of hours flown in darkness till it practically comes to night flying, a considerably higher degree of comfort will be necessary for the crew, whilst it will also mean a large increase in the means of navigation necessary for night flying.

Choice of Cargo

In the above, we remarked incidentally that one would have to reckon with the transport of mail, passengers and goods. The position adopted by the K.L.M. from the very beginning is that the cargo carried between Amsterdam and Batavia must be mixed. As this position has lately been repeatedly contested, it might be well to elucidate it here.

The basis, indeed, of the air service between Amsterdam and Batavia has always been, and is still to-day, the transport of mail, and it is exclusively the contract for the carriage of mail which has enabled the air line to operate first a fortnightly and afterwards a weekly service. The reference here is to an agreement with the postal authorities in Netherland, whereby the K.L.M. undertakes to transport mail to a maximum of 500 kg. (1,000lbs.) weekly in both directions, whilst the Post Office, on the other hand, agrees to pay for the transport of 500 kg. mail, even if this amount is not reached.

The position has thus become as follows. The payment agreed upon enables the K.L.M. to cover, to a large extent, the costs really made. On the other hand, the Post Office must endeavour to recover the sum thus expended from the public in the form of extra postage for air transport. When the Post Office receives 500 kg. mail for transport from terminus to terminus, it is able to cover its expenditure. Above the 500 kg. it begins to make a profit; below the 500 kg. it suffers a loss. At the present the latter is the case, as the mail transported from terminus to terminus amounts to about 285 kg. (575lbs.) weekly. On the other hand, mail is collected and delivered at various points *en route*, so that the total mail carried on certain stages already amounts to more than 350 kg. The rate of six gold centimes per 100 gram per 100 km., internationally agreed upon, serves as basis for the compensation paid for carriage of mail on the intermediate stages. Naturally, the more regular and rapid the service is the greater the inclination on the part of foreign postal administrations to make use of it. Expectations entertained with regard to the mail transport have, generally speaking, not been disappointed. When the weekly service was instituted one expected, during the first three months, an average of 150 kg. per flight, whilst in reality it amounted to 244 kg. Over the second and third quarter, the estimate was 200 kg. and the reality 238 kg. For the fourth quarter the estimate was 300 kg., which amount was not reached, the average was then 285 kg.

The proportion between the Netherlands mail carried by aeroplane and by boat is extremely favourable for the K.L.M., viz., 1 to 3; that is to say, that already the K.L.M. carries 25 per cent. of the total first class mail between Netherland and India.

The agreement made prescribes that the K.L.M. shall have no voice in mail arrangements made with foreign administrations or in the fixing of postal rates. The K.L.M., however, conceives its mail contract in the spirit that, on its side, it must do everything in its power—also by means of direct negotiations and propaganda abroad—to develop the transport of mail in order that this can become a paying proposition for the Post Office as soon as possible. A considerable increase in the mail transport resulted from the introduction of 5-gram letters, whilst recently a lower rate was initiated for letters up to 10 grams. If the K.L.M. had hitherto restricted itself exclusively to the transport of mail, neither party would have benefited. The journey would not be of shorter duration than it is now; the income of the Post Office would not have been bigger, or one might put it differently and say that the loss for the Post Office would not have

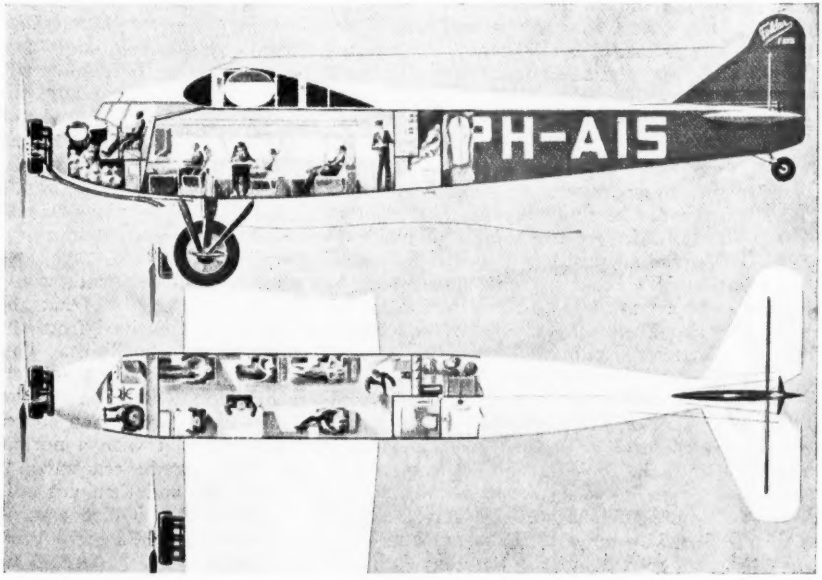


FIG. 2.

Interior of Fokker F XVIII machine (engines—three Pratt and Whitney "Wasp," 420 h.p. each), as in use on the weekly K.L.M. service, Amsterdam-Batavia. Carrying capacity: 1,000lbs. of mail, four passengers, crew of four. Radius of action: Seven hours=850 miles. Cruising speed: 122 miles/hour.

been less. As for the K.L.M. itself, the mail contract formed a solid basis for carrying out the flights where otherwise the company would also have suffered a loss. It is an erroneous idea to imagine that the transport of passengers has resulted in the choice of less rapid material than might have been possible. The K.L.M. is not interested in designs of rapid mail machines on paper, the qualities of which have still to be proved. In the construction of its material it is guided by the requirements demanded by the flights to India as these are at the present time. One of the chief requirements we have already mentioned, the equipment with three engines and the ability to fly with two. The following requirement, related to the system described above, was a crew of four, viz., two pilots, a

telegraph operator and a mechanic. A third requirement was the existence of sufficient comfort on board to enable the crew to rest during the flight. If, with these requirements in view, you sketch an aeroplane round a crew of four, you will arrive at the present shape which automatically leaves sufficient room for a few passengers and a quantity of freight.

What does one achieve with this transport over and above the mail? In the first place, one supplies an existing demand from the side of the public, and the assertion repeatedly made, without any proof whatever, that the time is not yet ripe for the rapid transport of passengers is completely refuted by the facts. The extra revenue from the transport of passengers and freight means not only that the K.L.M. suffers no loss in operating the service, but also that the Indian route requires no subsidy, apart from the mail contract. On the contrary, the profit made flows back into the national exchequer, which again means that the subsidy granted to the K.L.M. is finally considerably reduced. Although the Post Office still suffers a loss on the exploitation of this service, which means a loss of State money, on the other hand, considerable sums flow back into the national exchequer, and with the bigger aeroplanes these sums will also increase considerably. This is not the only advantage, however. With the increase of these sums, the postal contributions can correspondingly be reduced which finally means that the time will come when the public will have to pay less on postage. This can never be achieved when the company devotes itself exclusively to the transport of mail, though mail alone, at the actual postage, would suffice to pay the cost of transport on this particular line. The plans which, outside the K.L.M., are the subject of much discussion at the present moment, are based on the supposition that a rapid speeding up of the service, thanks to the operation of a rapid mail machine which has already been designed, would lead to such a considerable increase in the quantity of mail carried, that the Post Office would no longer suffer a loss and that the income derived from the postage paid by the public would suffice to cover the costs of the flight. This is a theory which has still to be proved. Moreover, this plan holds absolutely no prospect of future improvement, apart from the question whether a regular service with such a machine, with a small crew and insufficient comfort on board, will be possible. Over against that, we have the position that with a normal development of the mixed cargo transport, the same result can be reached in a short time by an increase of speed and longer flying stages, and then not only more favourable financial results can be achieved—for the Post Office as well as for the K.L.M.—but also, in addition to the mail transport, another important transport can be developed, viz., that of passengers and goods. There is no reason why a passenger should travel less quickly than a letter does. When the exchange of written thought between two points on this globe has become so important that speeding up by means of air transport is felt necessary, there exists doubtlessly the same necessity for a quick exchange of views in personal conversation and the need of quick travel between Europe and the Far East has been fully proved. The object aimed at with mixed cargo transport becomes therefore greater and of infinitely greater advantage. It is a short-sighted policy to consider present results alone, results which, to judge from the number of passengers carried, are undoubtedly becoming more favourable.

The K.L.M. intends in 1934 to cover the route between Amsterdam and Batavia in six days and trusts within a few years to be able to reduce this to four days. We shall return to this point again towards the end of this paper.

Description of Material

I have already pointed out how the first experimental flights along the K.L.M. Indian route were carried out, from sheer necessity, indeed, with material which was really not quite suitable for the purpose. The first mail flight with a triple-engined machine gave much better results, as the Fokker F VIIb machine

of that time—I am speaking now of a period already five years behind us—might be called an exceptionally good machine. The numerous world flights made with this type of machine, its exceptionally good flying qualities and general practical serviceableness, made the choice for the K.L.M. not a difficult one. The great success of the F VIIb machines over the whole world, a success by no means the least with the K.L.M., led other air transport companies to adopt the same type, and so we see many companies, even to-day, regularly using these machines and exploiting them with entire satisfaction. Five years is a long time; a very long time, indeed, for a new means of communication still in process of development. If a certain type of machine is operated during five years, it is a proof that it is very good, both from a technical and economic point of view.

When, on October 1st, 1931, the fortnightly service was changed into a weekly one, it was originally flown with F VIIb's and Fokker F XII's alternately, but in April, 1932, the F VIIb machines, becoming too small, were withdrawn from the service, which was subsequently exclusively operated with F XII machines. The K.L.M., however, did not rest there, and however excellent the qualities of the F XII, urged upon the N.V. Nederlandsche Vliegtuigen Fabriek (Fokker) the necessity of developing a still speedier machine which must also be equipped with the same Pratt and Whitney Wasp C. engines of 425 h.p., with which the F XII had obtained such brilliant results. These machines, type F XVIII, entered the service in the course of 1932. The K.L.M. has now five of this type of machine. The whole weekly service is operated with these five machines and with two F XII machines, one of which is always held in reserve and revision, whilst in India a machine is always automatically in reserve, as normally each machine remains ten days at Bandoeng and the service is a weekly one.

The machine and the engines naturally form such an important factor in the exploitation that I must dwell somewhat longer on it. If we pass over the F VIIb machines as being of merely historical importance—as far at least as the Indian route is concerned—then we see in March, 1931, thus before the beginning of the weekly service, the first departure of a F XII for India. I participated in this flight as passenger in order to inspect the intermediate stations and to confer with our sister company, the Royal Netherlands Indian Air Lines. I was immediately struck with the amount of room afforded each passenger, the spacious cockpit which facilitated the work of the crew and the smooth running of the American air-cooled engines, specially suitable for service in all weather conditions, sand storms and monsoon rains, owing to the enclosed valve mechanism, the protection against rain of the carburettor heating, magneto covers and the adjustable carter shutters, which make it possible to regulate the oil temperature to a certain extent. The first F XII machines were not provided with Townend rings; the subsequent adoption of these rings proved a great success. Not only was it possible to attain a considerable saving of fuel with the same speed, but these rings proved to possess the additional advantage that they eliminated to a considerable degree the annoying disturbances in the wireless caused by the sparking plugs. This, however, is only an incidental advantage and it should not be concluded that the screening can be completelv done away with, as many of the other parts, more especially the magnetos themselves, can cause trouble.

After the first F XII machines had been delivered by Fokker an inquiry was made, on the initiative of the K.L.M. but in collaboration with Fokker factory, into the question of how far it would be possible to increase considerably the loading capacity of the subsequent F XII machines, on the one hand, by a higher total weight; on the other, by a lowering of the empty weight. These efforts were crowned with success. The empty weight was reduced by the use of electron for the petrol tanks and for the cowling. The carpentry work in the cabins was made considerably lighter and the heavy sash windows with handles and

mechanism were replaced by sliding windows, by which it was also possible to eliminate the heavy ply-wood which shut off the window mechanism from outside. The steel cabin chairs were replaced by electron chairs. Although these chairs were much lighter, we were regretfully compelled again to replace them with steel furniture, as in the tropics they developed symptoms of corrosion. Chairs made of hydronalium constitute a point for consideration. As a very important step towards an improvement of the F XII machine must be mentioned the use of bakelite ply-wood, which is the ideal material for the tropics, as it is in a high degree immune to the influence of water. Moreover, this material can be supplied in extremely thin plates of 0.6 to 0.8 mm., with the result that a considerable economy of weight can be achieved on the wing covering when this material is employed on the less stressed portions of the wing, for example, behind the rear spar. The suspension with Sandow rubber may also be regarded as obsolete. Rubber, indeed, is a very unsuitable material for use in the tropics. The most recent F XII machines and the F XVIII's are provided with Messier-oleo pneumatic landing gear struts.

To ensure regularity in operating the route, engines of great reliability are absolutely necessary. If the exploitation is to be favourable from an economic point of view, however, it is further necessary that the maintenance costs of the engines should not be too high. The modern American engines can easily make periods of 400 to 500 hours, but the K.L.M. wishes to take no risks on a long and difficult route like that to the Far East, and the Wasp engines after two round trips, *i.e.*, after 290 hours, are sent to the motor shop of the K.L.M. for an overhaul.

Ever since it was founded the K.L.M. has always taken aeroplane and motor repair work in hand itself and even carried out important repairs and reconstruction of its machines in its own workshops at Waalhaven. This policy has proved the correct one and the cheapest, whilst in cases where urgency is necessary, the time otherwise necessary for transport to the factory, for dismantling the machine and mounting it again, is saved.

The aeroplanes now in use require much less maintenance than those with which the K.L.M. began operations in 1921. The experience accumulated during twelve years of air transport has been utilised in the construction of the F XVIII machines, thanks to a close co-operation between the K.L.M. and the aeroplane factory. Where formerly, for example, seven years ago, a machine could only reach 500 flying hours in one year at the cost of great efforts and much work, various machines can now, in 1932, attain 1,000 flying hours. This result is due in the first place to the fact that the period between two revisions has been increased from between 250 and 500 hours to between 1,800 and 2,500 hours, with a slight overhaul after the first 1,000 hours. Naturally, the machines must then be expertly flown and inspected, whilst the normal daily routine work must not be neglected if the reliability and regularity is not to suffer in the long run. Although the machines require comparatively little costly repair work, it is at the same time a fact that owing to the use of all kinds of devices they are becoming more and more complicated. I refer here especially to the steadily increasing number of instruments, the rather complicated electric installations and also to the complications necessary for flying in fog or in darkness. Further, there is the whole wireless installation and eventually a D.F. installation. Then again there are the handles, knobs, switches, etc., which must be served by the pilots, the number of which is continually increasing, so that it is becoming evident that we shall shortly have to proceed to the installation of various switch-boards and instrument boards which will only partly be under the hand and the observation of the pilots. We shall then have a sort of engineer's cabin, eventually combined with the place where the wireless operator sits, similar to that on the DO X. When in the future we see the adoption of retractable landing gear, variable wing camber, automatic steering gear and engines accessible in

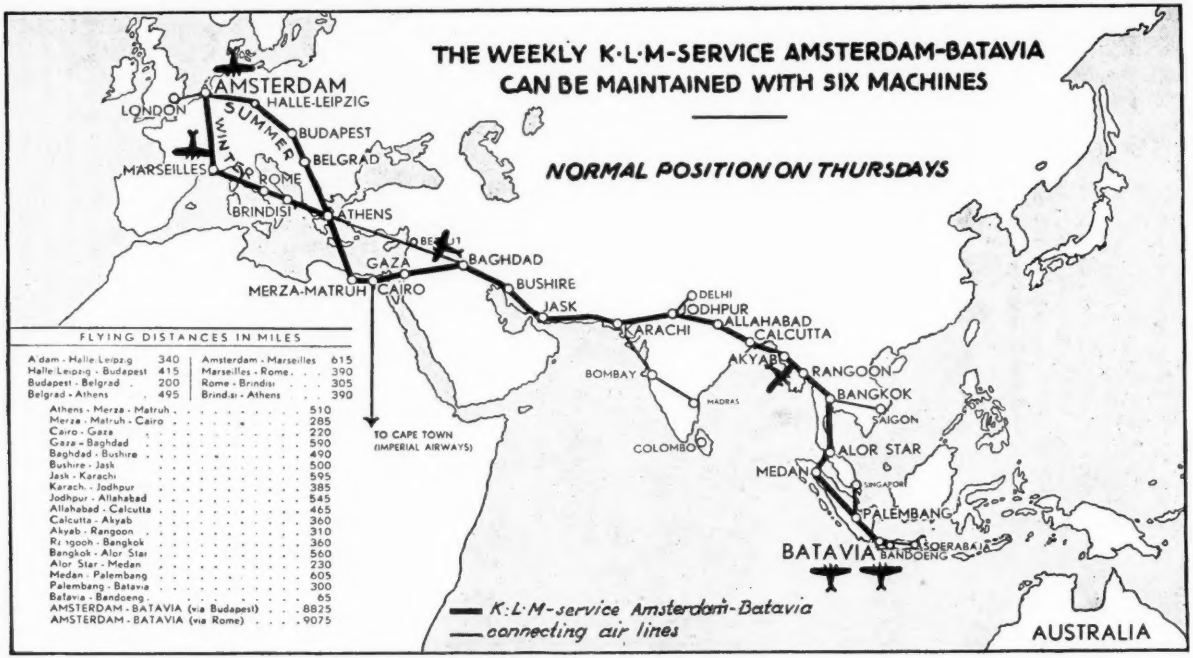

THE WEEKLY K·L·M-SERVICE AMSTERDAM-BATAVIA
CAN BE MAINTAINED WITH SIX MACHINES
NORMAL POSITION ON THURSDAYS
AMSTERDAM
HALLE-LEIPZIG
LONDON
SUMMER
WINTER
BUDAPEST
BELGRAD
MARSEILLES
ROME
BRINDISI
ATHENS
BEYROUT
GAZA
BAGHDAD
MERZA-MATRUH
CAIRO
BUSHIRE
JASK
DELHI
ODHPUR
ALLAHABAD
KARACHI
CALCUTTA
AKYAB
RANGOON
BOMBAY
MADRAS
BANGKOK
SAIGON
COLOMBO
ALOR STAR
MEDAN
SINGAPORE
PALEMBANG
BATAVIA
SOERABAJA
BANDOENG
TO CAPE TOWN
(IMPERIAL AIRWAYS)
K·L·M-service Amsterdam-Batavia
connecting air lines
AUSTRALIA
FLYING DISTANCES IN MILES
A'dam - Halle-Leipzig 340
Halle-Leipzig - Budapest 415
Budapest - Belgrad 200
Belgrad - Athens 495
Amsterdam - Marseilles 615
Marseilles - Rome 390
Rome - Brindisi 305
Brindisi - Athens 390
Athens - Merza - Matruh 510
Merza - Matruh - Cairo 285
Cairo - Gaza 220
Gaza - Baghdad 290
Baghdad - Bushire 490
Bushire - Jask 500
Jask - Karachi 595
Karach. - Jodhpur 385
Jodhpur - Allahabad 545
Allahabad - Calcutta 465
Calcutta - Akyab 360
Akyab - Rangoon 310
Rangoon - Bangkok 360
Bangkok - Alor Star 560
Alor Star - Medan 230
Medan - Palembang 605
Palembang - Batavia 300
Batavia - Bandoeng 65
AMSTERDAM - BATAVIA (via Budapest) 8825
AMSTERDAM - BATAVIA (via Rome) 9075

FIG. 3.

flight—and I am convinced that this will be necessary for the very large machines in future—then it is certainly desirable that the pilots should only have the steering mechanism and the navigation instruments under their personal control. However, I will not venture too far into the future.

The starting of the Wasp engines was originally made with Eclipse energy starters which were made to revolve by hand with the help of a handle. Although the starter as such proved efficient, the work of turning it on in the tropics demanded so much effort on the part of the crew that it proved desirable to replace these starters by others. The choice of the K.L.M. fell on the starting pistols which had given such satisfaction to the K.L.M. when used with the Jupiter and Titan engines.

From the British side this method of starting the engine has been subjected to some criticism, and with reference to this I would just say that this system of starting up the engines has been employed by the K.L.M. tens of thousands of times without any detrimental influence becoming apparent on the cylinder or on the main connecting rods or pistons. Further, there is the fact that this starter is exceptionally light and uncomplicated. Failure can hardly ever be ascribed to the starter, but almost always to too little priming when performed by personnel without sufficient experience to reckon with the temperature of the engine or the outer air. The K.L.M. has improved the starting pistol considerably by constructing a valve of its own design, and since the pistol has been used in combination with the strong spark of a hand magneto, no lighter or more reliable starter is conceivable. It may make on the passengers a very businesslike impression to start the engines simply by pressing a button; the great disadvantage remains that electric starters involve great complications, whilst further, extra measures have to be taken against the danger of fire. Moreover, the increase of weight and consequently of loss in pay load, especially with multi-engined machines, is considerable, and one has to fall back on large accumulator batteries with a limited period of efficiency.

Tail-wheels are now fitted to all F XII and F XVIII machines. At first a few pilots entertained a certain prejudice against these, as they had too little confidence in the wheel brakes. When these showed themselves quite reliable, however, and the capacity to manœuvre proved much greater, the tail-wheels constituted a great improvement. In the case of small aerodromes it was possible to wheel round much closer to the edge of the field and start under full gas, after loosening the brakes as soon as the engines had attained their maximum revolutions. Another advantage is that on the aerodrome the machine can be rolled into and out of the hangar with very little labour so that it is possible to economise in the wages of personnel. Finally, there is the fact that the tail-wheel greatly facilitates manœuvring in the vicinity of petrol tanking places, which minimises delay at intermediate stations.

Extensive experiments were made with wheel cowlings, but although to the eye the shape appeared very favourable from an aerodynamic point of view, the increase in speed was only 1 to 2 km. an hour. Moreover, wheel cowlings are very unpractical, easily damaged and in certain circumstances even dangerous. When it further finally appeared that they were absolutely useless on muddy ground, they were definitely given up.

Trouble was experienced in dust storms with exterior steering cables. The rudders became sluggish in movement and continual cleansing brought only temporary improvement. With the F XVIII machines, this difficulty was eliminated by leading all the steering cables inside the body. This renders the possibility of inspection somewhat more complicated. In the ceiling of the cabin, hatches have been made for the inspection of the steering cables.

The body of the F XVIII is narrower than that of the F XII and rounded on the top.

All machines for the Indian route are provided with two gyroscopic turn indicators, one German "Askania" and one French "Badin Pioneer," the latter being combined with an airspeed indicator. All machines are further provided with longitudinal inclinometer and a climbing speed gauge. Experiments were also made with Sperry artificial horizon and a Sperry directional gyro. The general adoption of the Sperry horizon is one of the last improvements destined to facilitate blind flying. For the rest, blind flying with the F XVIII machines is not exacting, as the inherent stability of the machine is very great.

The Dutch authorities are rather strict in fixing the degree of inherent stability, and the study by the Governmental Research Department of this point has led to better ideas in this sphere, which is all to the advantage of the purchasers of machines, although it causes much racking of brains on the part of the constructors.

All machines are equipped with fixed antennæ, which constitutes a double advantage: First, the wireless can be used when the machine is flying very low or is standing on the ground; and secondly, the chance of being struck by lightning is much less than with the use of the trailing antennæ. This latter danger is a point which is still being studied. A protective device is still in course of being tested. Attention is being given to the problem of the drawing off of static electricity and several parts of the machine have an extra earthing or are at least extra electrically connected with the main construction of the body, more especially with the engines, as it has appeared that the drawing off of static electricity can very well take place via the sharp and rapidly rotating propeller blades.

The use of cylinder temperature indicators is perhaps of sufficient interest to justify a few remarks. These very useful instruments are not only of importance when the machine is in an experimental stage, they give also a timely warning against overheating and where this eventually may be due to the use of less suitable fuel, it also constitutes on the Indian route a control instrument as regards the quality of the petrol supplied.

The Fokker F XVIII, flying fully loaded (7,550 kg.) on any combination of two engines, has a service ceiling of 1,700 metres. Under the term service ceiling is meant the altitude at which the climbing speed still amounts to ½ metre per second.

The K.L.M. was one of the first air transport companies to use metal propellers. Originally, these were Reed propellers, but later we gave the preference to adjustable pitch standard steel propellers. We are convinced that with the prevailing weather conditions on the Amsterdam-Batavia route, *i.e.*, heavy rains in the tropics and hailstorms in Europe, only metal propellers can stand the strain with the actual 1,700 to 1,750 revolutions per minute.

It may be asked whether the dust storms which are met with now and then result in extra wear and tear, more especially as regards the engines and the turning points of the machines. Fortunately, this has not proved to be the case, which is probably due to the fact that the desert sand is really more of the nature of dust and extraordinarily fine in its composition. These dust storms, however, render navigation more difficult and make the machines exceedingly dirty, as the dust penetrates almost everywhere.

The influence of the tropical sun and the fact that the machines had very often to spend the night in the open air, exercised at first a detrimental effect on the paint work, especially on the varnish of the wings. A very considerable improvement was obtained, however, by using aluminium-coloured nitro-varnish and aluminium valspar lacquer for the older machines, both of which can be applied with the paint syringe.

Finally, just a word concerning the equipment on board and at the intermediate stations. I have already pointed out that at the intermediate stations

there is no K.L.M. staff and that the crew are therefore obliged to rely solely on foreign personnel, on our agents and on themselves.

In order to be able to carry the largest possible pay load, we have restricted to the greatest possible extent the number of reserve parts, tools, and articles of equipment on board. These still form a respectable quantity, however, because it is necessary to have on board articles of equipment which do not lend themselves to being kept in stock at the stations owing to the fact that they may be needed in the air or at stations where no tool chests are present. In total we have about 200 kg. on board, including, however, ten large thermos flasks and a stock of tinned food for use during the journey containing 20 kg. emergency rations. With a view to unexpected forced landings in the desert or in the tropical forest, we have, in addition to the emergency rations, also tins with drinking water (25 to 30 l.) on board and also a distilling machine to render dirty water suitable for drinking. Also with a view to forced landings en route, the machines are provided with mosquito curtains to be used over night in or outside the machine. Of course, there is also a medicine chest with instructions for use and a very complete chest with wound-dressing requisites.

At the chief stations, Cairo, Baghdad, Karachi and Bangkok, we have deposited extra supplies, in addition to the usual station chests distributed over the 22 stations along the route. Moreover, we have at several stations our step-ladders, our filling material, carts, grease squirt installations, and larger reserve parts, such as motor cylinders, propellers, wheels and tyres.

Wireless

On the test flights and during the first period of the regular service, the route Amsterdam-Batavia was flown without wireless. The chief reason for this was that at that time a wireless installation would only have been of use on the European section of the route, as farther on the necessary ground stations were practically non-existent. Another reason was that the loading capacity of the machines with which the K.L.M. operated on this line was comparatively slight and difficulties would have arisen in connection with the extra weight and the necessary room for a wireless installation and operator. When experiments were made, it was immediately demonstrated that although we had become accustomed in Europe to the advantages of wireless *under certain circumstances* (in unfavourable weather and for safeguarding a few short sea stages, such as the crossing of the Channel), this expedient on the Indian route was of great value *under all circumstances*. These experiments were undertaken owing to the establishment of British wireless stations on those sections of the route where sand storms and monsoon rains made them most necessary, whilst a powerful impetus was also given in this direction by the necessity of rendering the passage of aeroplanes over the Mediterranean Sea as safe as possible. Since it has proved possible to keep in wireless touch with radio stations over the whole route, and since it has appeared that monsoon rains by no means constitute such a difficulty for wireless as was anticipated, wireless became indispensable. Not only as regards direct safety and regularity (weather reports, information concerning the condition of aerodromes, warnings against sand storms, violent monsoon rains and thunderstorms), but also in other respects, the advantages surpassed all expectations. Direct communication between the aerodromes (such as exists in Europe) being almost generally lacking, wireless made it possible to inform the K.L.M. agents and the aerodromes, customs, passport and other authorities of the expected hour of arrival. This led to a smoother working of the whole ground organisation and guaranteed a better service to the passengers.

Practically speaking, in the series of wireless ground stations between Amsterdam and Batavia, lacunæ no longer exist, which means that the machines are almost always in touch with two stations, one in front and one behind. In some countries, it is true, the personnel at the stations show some shortcomings

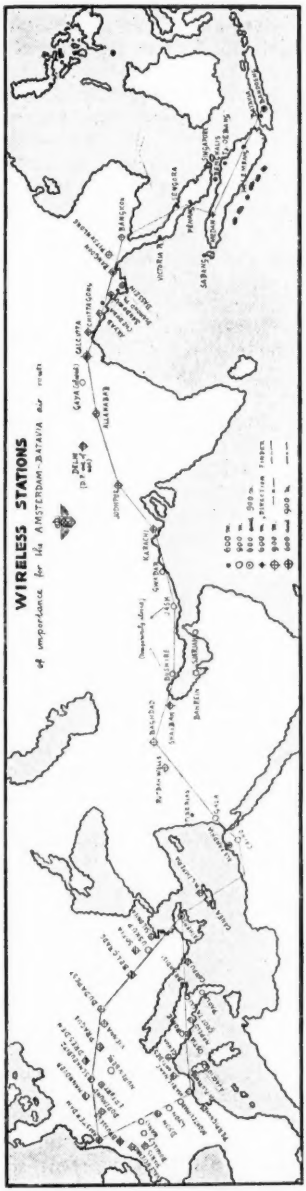

WIRELESS STATIONS
of importance for the AMSTERDAM-BATAVIA air route

FIG. 4.

as regards the routine in working with aeroplanes, but also this part of the wireless organisation is improving every day. Difficulties are still experienced above the jungles of Sumatra and Burmah, where absorption phenomena detrimentally affect the distance over which communication is possible. For this the short wave may prove a remedy. Generally speaking, it can be said that the average working sphere of the wireless installations used on board the K.L.M. machines amounts to 300 km., whilst communication over distances of 800 km. are by no means exceptional.

Once it was decided to introduce wireless on the Indian machines an effort was made for a time not to increase the original crew, consisting of two pilots and one mechanic, but to charge the second pilot with the wireless service. It appeared, however, that these second pilots, although they had passed the required examination, did not possess the practical experience necessary to correspond fluently in difficult circumstances. The greatest objection, however, was that just when wireless assistance was most necessary, that is, in bad weather, the presence of both pilots in the cockpit was desirable. At the present time a professional wireless operator (detached by the K.L.M. from the Corps of Wireless Operators of the Mercantile Marine) forms a permanent member of the crew.

In air traffic an important section of wireless work consists of direction finding for navigational purposes. On the Indian line the K.L.M.—with the exception of one experiment with a direction-finder on board—from the very beginning followed the system adopted in Europe of bearings from the ground stations. This was possible owing to the fact that the British also followed this system and had equipped a large number of their ground stations with direction-finders. This system has the advantage that it restricts the weight on board whilst the drawbacks sometimes experienced in Europe, when during unfavourable weather a great number of machines simultaneously ask for bearings, do not exist on this line. On the other hand, the determining of positions by cross bearings can very seldom be done on the Indian line as generally no stations lie athwart the flying route, so that the direction-finding can only lead to determining the course to the station of destination and not to cross bearings. In general, however, this complement to dead reckoning is quite sufficient—only in the case of approaching an aerodrome which is covered in a sand storm or a heavy monsoon shower and which is equipped with a wireless station without direction-finder, a D.F. device on board, such as is employed in the machines of the French Air Orient Company, would have advantages.

Very interesting are the experiments being made at the present moment at Rangoon with a " wireless beacon," that is, a station that sends out a rotating beam of which the period of rotation is known. At the moment when the direction of this beam is north, another undirected signal is given. With the help of a stop-watch, the position of the machine to the ground station can be determined by measuring the difference in time between registering the undirected and the directed signal. The results of these experiments are not yet known.

Navigation

The navigation on the Amsterdam-Batavia route is in principle identical with that on the European lines. The only difference is that the factor of dead reckoning plays a greater *rôle*, owing to the greater distances, less diversity in the nature of the ground surface of many regions (sea stages, deserts, extensive plains in India, tropical forests) and also owing to the less elaborate maps. Wind corrections, therefore, play here a more important *rôle*, for which reason the K.L.M. machines on this route are equipped with a special and extremely simple arrangement for drift measuring. This arrangement consists of nothing more than a round hole covered with glass in the floor between the two pilots' seats and within which a ring, provided with two threads running parallel with the

length of the machine, can revolve. By means of a handle each of the pilots, from his seat, can so manipulate this ring that fixed points on the ground or the tops of waves, pass precisely along these threads. An indicator fastened to the axis then gives the number of degrees of drift to starboard or port. The method of measurement applied by the K.L.M. pilots with the help of this simple instrument, the effect of which is that the influence of side wind on the *course* followed is completely compensated, but whereby some uncertainty with regard to the *ground speed* remains, proves in practice absolutely sufficient, with sea crossings of 400 km. and desert stages of still greater dimensions, to guarantee arriving accurately at the destination desired and that notwithstanding winds which repeatedly change in direction and velocity. A theoretically absolute determining of direction and velocity of the wind, of ground speed and angles of correction which is only possible by measuring drift on cross courses, proves here unnecessary for a practically sufficient absolute result.

During navigation in or above the clouds, whereby for one's dead reckoning no side wind corrections can be applied, the wireless direction-finding stations at the places of destination naturally play a great *rôle*.

Maps

On the route Amsterdam-Batavia, the K.L.M. makes use of the following map material (chiefly supplied by the firm of Stanford in London).

Topographical Maps.—In Europe: Survey maps 1 : 1,000,000.
Flying maps 1 : 300,000 or 1 : 200,000.
Outside Europe: Survey maps 1 : 4,000,000.
Flying maps 1 : 1,000,000.

Sea Charts.—Of all coasts and sea passages lying on the route (British Admiralty Charts, on a scale as far as possible between 1 : 500,000 and 1,000,000).

Details.—Descriptions and sketches of all aerodromes and suitable grounds in case of forced landings, collected in an atlas. To which are added extracts from the various prescriptions and prohibitions in various countries, data concerning rainfall, sunrise and sunset tables, etc., etc.

Weather Conditions

Weather conditions influencing the safety or the regularity of the Amsterdam-Batavia service are as follows:—

1. *Fog and low-lying clouds above hilly or mountainous country, with the consequent danger of ice formation.* Practically, this applies only to the European section of the route (between Amsterdam and Crete) and then specially in the autumn and winter. (Morning mists which prevail about sunrise and which occur in places like Cairo, Baghdad, Bushire, Calcutta, etc, cannot be regarded as really disturbing factors.)

2. *Sand storms,* or to put it more correctly "dust storms," which during the spring and summer occur between Rutbah Wells and Jodhpur. These can reach a height of more than 2,000 m. (6,000ft.), and reduce visibility to 30 m. (30 yards). When such a storm is raging at the place of destination, landing is impossible with technique as it stands to-day, even with the help of wireless guiding.

3. *Monsoon rains and tropical thunderstorms,* which occur in the summer and autumn between Karachi and Batavia, but which, generally speaking, are only regarded as serious between Allahabad and Penang.

The above sequence also applies to the degree of hindrance caused by these factors on the Amsterdam-Batavia service. Worthy of note is the fact that, of the three factors mentioned above, the monsoon rains were originally the most feared, but experience has proved that they have the least influence on the regularity of the service. It is true that on one or two occasions exceptionally

severe monsoon rains have placed a K.L.M. machine in a dangerous situation, but have comparatively seldom caused delays of any importance, such as are sometimes caused by sand storms or mist. In the few cases where monsoon rains caused serious delay, this was due not to difficulties experienced in flight—flying, indeed, was quite possible—but to the fact that it was impossible to land on the aerodromes, which were flooded. (One must remember that in Bengal there frequently falls more rain in a month than in West Europe *in a year*. And West Europe, as a rule, has little reason to complain of drought.)

One thing in favour of maintaining, as far as possible, a uniform duration of the journey throughout the various seasons of the year is that the three obstructive factors, fog in Europe, sand storms in the Middle East and monsoon rains in the Far East, practically follow each other and seldom coincide. If a travel scheme is thus drawn up with a small margin—one day, for example—in the theoretically necessary number of flying days, there is a considerable chance that time lost by reason of one of these three factors can be recovered on another section of the route.

Normally speaking, strong wind cannot of itself disturb the regularity of this K.L.M. service. On all stages the quantity of petrol carried by the machines allows of such a margin that, practically speaking, it is impossible that an aeroplane should not be able to reach its destination owing to contrary winds alone. The travel scheme (that is, the daily stages) allows in its turn for such a surplus of daylight that every prescribed stage of the journey can be covered before sunset, even with a strong headwind. Once, indeed, a violent storm caused such difficulties in bringing a machine out of the hangar that the pilot judged the risk of damaging the machine too great and therefore postponed his departure. In two cases also it has happened that a storm, which assumed the velocity of a gale, compelled a K.L.M. machine to fly a shorter daily stage.

A heavy sea, also the result of storm, and which can cause serious delay in the case of air lines which employ seaplanes, does not affect the K.L.M. as it does not use seaplanes.

Meteorological Reports

The organisation of the meteorological service on the Indian route on behalf of air navigation cannot be compared with what has been achieved in this sphere in Europe, but even here it is possible to notice an improvement. It is naturally extremely difficult, in this special branch of meteorology, to organise co-operation between so many countries where applied meteorology is in itself so little developed. The international air traffic ought to be grateful for the excellent work performed in this sphere by the British R.A.F. wherever its squadrons are stationed and for the broad-minded spirit with which it makes its observations and forecasts available by means of its own wireless stations.

One class of data which, outside of Europe, are still much too uncommon, are those of wind velocities at various altitudes, of such enormous importance for favourable navigation.

The ideal task of a meteorological service on behalf of air traffic in tropical countries may be summarised in the following points:—

(*a*) Observations made several times a day and communicated by wireless, on request, of wind velocities at altitudes prevailing at the greatest possible number of places;

(*b*) Idem for barometrical pressures;

(*c*) Wireless communication, on request, at any moment of the day of the following data regarding every aerodrome: Visibility, height of clouds, direction and velocity of wind on ground level, rainfall, condition of the landing ground;

(*d*) Warning to machines in the air against heavy rains, thunderstorms and sand storms;

(*e*) Communication, on request, of weather forecasts;

(*f*) Availability at the aerodromes of weather cards and synoptic weather reports.

In British India a meteorological service for air traffic is being conscientiously developed along these lines. It is true that much has still to be done and lack of the necessary funds makes complete achievement improbable in the near future, but the K.L.M. has great admiration for what, with extremely scanty means, has already been accomplished in that country and for the very active interest shown in aeronautics by British-Indian meteorologists.

Aerodromes

The aerodromes situated along the route Amsterdam-Batavia are generally not smaller than those in Europe, but here, relatively speaking, *larger* grounds are necessary. By this is meant that owing to the unfavourable condition of the ground, heavy rainfall and other circumstances, the whole surface of the aerodrome frequently cannot be used by heavy machines. The landing grounds also are sometimes encircled with obstacles which on a busy European aerodrome would not be tolerated. The chief reason, however, why in the tropics relatively larger aerodromes are necessary than in Europe, lies in the greatly reduced starting capacity of aeroplanes in hot weather, more especially when it is accompanied—as it very frequently is—by absolute calm.

On board the machine there are very extensive graphics and data relative to the influence of temperature and atmospheric pressure on the taking-off and flying qualities of an aeroplane, a factor of very great importance in the tropics and on aerodromes at a high level. There is naturally also a list of all aerodromes, places suitable for forced landings and intermediary stations, with their height above sea level.

Outside Europe ground lighting—apart from what is improvised—is only found at Baghdad and Karachi. Sheds, able to accommodate a K.L.M. machine, are—outside of Europe—available at Gaza, Baghdad, Karachi, Calcutta, Rangoon, Medan, Batavia and Bandoeng. At Jodhpur such a shed is in course of construction.

Petrol-filling installations, *i.e.*, hand pumps, are now available on all important aerodromes and the average time spent in tanking is only 45 minutes. Along the whole route the supply of petrol is regulated by the companies composing the Shell group. These have performed exceptionally praiseworthy organising work and have by no means restricted their task to supplying petrol, but have extended it to collecting data concerning aerodromes, available routes, etc. The K.L.M. owes much to the assistance they have rendered on the Indian route.

Personnel

As already stated, the K.L.M. machines on the Amsterdam-Batavia route have at the present time a crew of four, viz., a first pilot (commander), a second pilot (also charged with the administrative work on board and with the care of the mail), a mechanic (who during the flight must also perform some simple steward's work) and a wireless operator who, on the night stops, must also assist the mechanic in daily work of keeping machine and engines in good condition.

Little can be said about the training of the wireless operators as the K.L.M. takes these over, already trained, from the mercantile marine. All that is necessary to make these operators suitable for their work with the K.L.M. is to explain to them the nature of the work they will be required to perform.

The board engineers are selected from the most competent of the personnel in the workshops of the K.L.M. A long training is necessary before these can be charged with this responsible and self-reliant function.

The training of the board engineers for the Indian route takes place at Schiphol and Waalhaven. The mechanics considered suitable for board engineer on the Indian route are medically examined by a K.L.M. doctor, and if passed by him are placed for a shorter or longer period in the motor section at Rotterdam, after which they are again transferred to Schipol to serve as monteur in the repair section for the Indian machines where they, in addition, receive the necessary instructions.

The chief engineer nominates such an expert monteur for an examination in order that he can acquire a governmental licence.

If he obtains this certificate, the monteur is temporarily told off as board mechanic on the European route in order to gain flying experience and at the same time to judge whether he is a good airman.

Afterwards, when necessary, he is transferred to the Indian route as board engineer.

It has appeared that more cases of sickness occur among the board engineers on the Indian route than among the other flying personnel. The reason for this will partly lie in the more comprehensive nature of their work and partly in the circumstance that the medical examination is less exigent. As soon as the number of those available is sufficient, the selection can be made more strict. At the end of the flight the mechanic, if necessary, is again examined by the K.L.M. doctor. The doctor collects statistics concerning the whole of the flying personnel and is thus able to state whether a mechanic, for example, is physically more fatigued after one Indian flight than after another.

The training of the aviators destined to serve, in the first place as second pilot and probably later on as commander, on the Indian line is naturally of the greatest importance. It goes without saying, in view of the multiplex nature of the task of the pilots on the grand trunk lines of the air, that this training must answer the highest requirements. In addition to first class flying ability and a thorough knowledge of technique and navigation, they must also possess administrative and commercial insight, a knowledge of languages, tact in intercourse with passengers and with all sorts and conditions of personnel at the various stations and in, last but not least, maintaining the necessary sense of discipline on board. All this means a combination of requirements which, in their many-sidedness, are certainly not less than those demanded of the most highly trained ships' officers. It is remarkable how the commanders at present available and who really were not trained along these lines, accommodate themselves generally in masterly fashion to their task, from which it appears—whatever may be said about training—that what matters first and foremost is character, aptitude and practice. The pilots now serving with the K.L.M. were drawn, without exception, from the flying services of the Navy and the Army, in which they had risen to the rank of officer or non-commissioned officer. In the present transition period, during which at the same time, the pioneer work on the Indian line must be carried out—during a period, therefore, when the highest requirements are demanded of the flying personnel, it was the task of the K.L.M. to transform these military aviators into suitable officers for world air traffic. More and more, however, the conviction is gaining ground that the training ought to be made more systematic and on the lines as required for other means of communication. Last year an experiment was begun on a small scale with a number of pupils of the Naval Institute at Amsterdam, who, in addition to their course of instruction for mate's certificate, follow a complete course of instructions for civil air pilot. Naturally, it is not yet possible to give the results of this experi-

ment. In addition to passing through a three years' course at the high school and a two years' course at a secondary technical school, a complete course of training for officer in the mercantile marine coinciding with training for air pilot, is considered desirable. An appointment as second pilot with the K.L.M. can then follow, in which function the further necessary training can be completed.

Health and Hygiene

One of the reasons which contributed to the adoption of the principle that the same crew should carry out the journey from terminus to terminus, was the consideration that this system was favourable to the health of the crew, and experience has shown that the rapid transit through various climates, followed finally by a long rest in a favourable climate like that of Netherland and that of the hill station of Bandoeng in Java, exercises the least unfavourable influence on the constitution of the crew. The most common ailments experienced en route are intestinal trouble, abnormal heat with the danger of sunstroke and heat-stroke, malaria, and finally, as long as the degree of comfort is still limited, general fatigue which—as long as the crew remains so small—can be accompanied by moral fatigue. As the crews are inoculated against typhus and cholera these diseases constitute no real danger. Lately, inoculations also take place against dysentery. With regard to fatigue, a considerable improvement is achieved by better means of navigation, more opportunity of moving about in the aeroplane and the easier handling of the machine, although naturally flying in unfavourable weather conditions, such as fog in Europe with the danger of ice formation on the machine, sand storms, monsoon rains, heavy thunderstorms and gales, still demand an exceptional heavy physical and moral strain. The intestinal trouble also, more especially in summer, continues to threaten the crew, so that the rule was instituted that the crews must regularly submit to a medical examination at Bandoeng. Against malaria there are prophylactic medicines, of which chinoplasmine has proved the most useful (one tabloid daily of 300 milligrams).

Against sunstroke, the crews protect themselves in the first place by wearing special spectacles with Crooks or Zeiss glasses, which absorb the chemically working light rays (50 or 75 per cent.). Pith helmets are worn against the heat.

Although cases of sickness nave occurred en route, the number of delays caused—even slight ones—is extremely small.

Results Achieved

Regularity.—The degree of regularity attained is shown by the accompanying graphics.

TRAFFIC IN 1932.

Mail, east-bound	14,069 kg.
,, west-bound	14,435 ,,
Total ...	28,504 kg.
Passengers, east-bound	215
,, west-bound	231
Total ...	446
(Passengers on intermediate stretches included.)	
Freight, east-bound	2,385 kg.
,, west-bound	3,100 ,,
Total ...	5,485 kg.

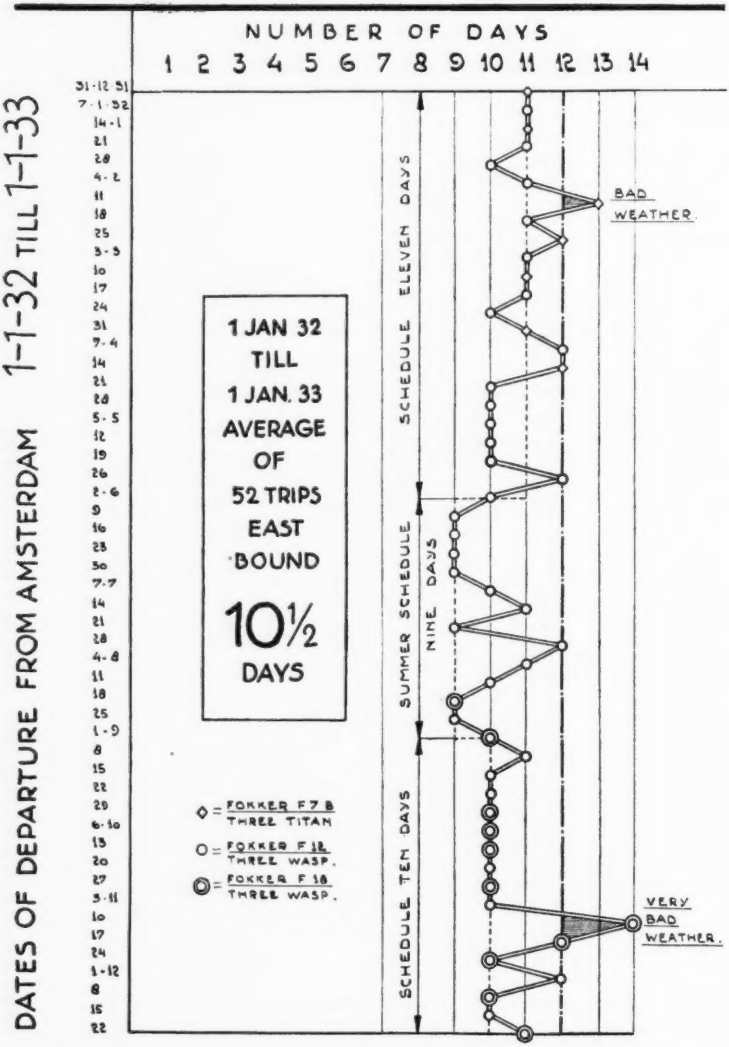
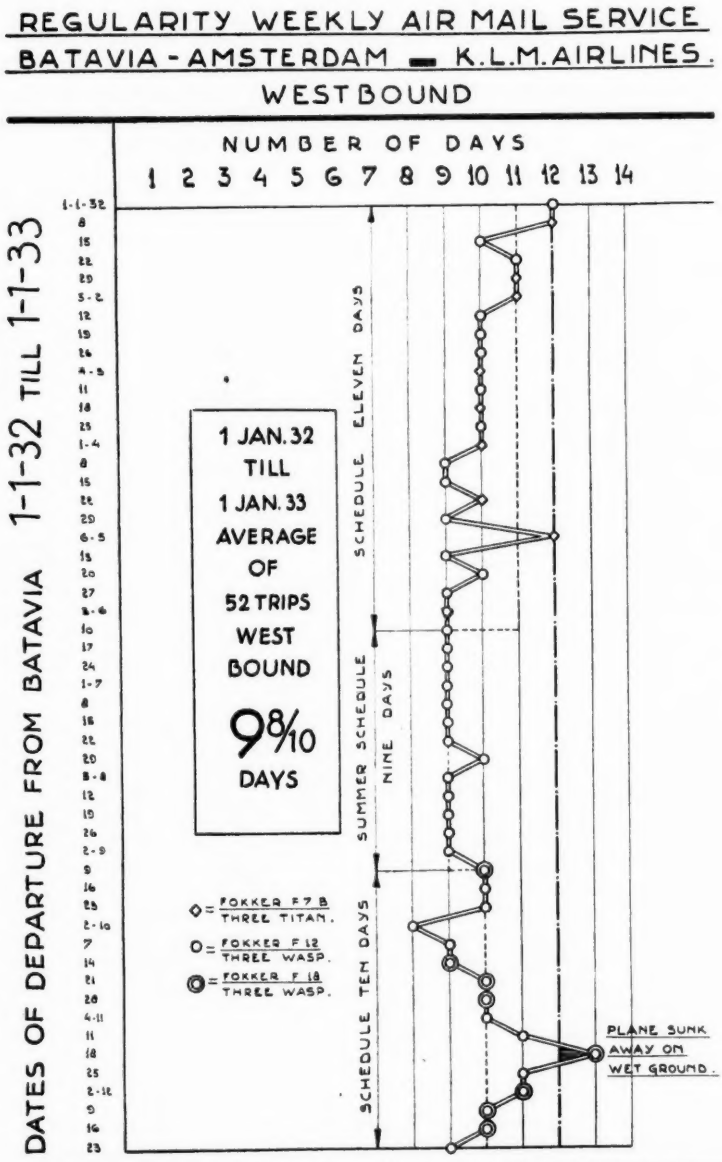

REGULARITY WEEKLY AIR MAIL SERVICE
AMSTERDAM - BATAVIA — K.L.M. AIRLINES.
EAST BOUND
NUMBER OF DAYS
1 2 3 4 5 6 7 8 9 10 11 12 13 14
DATES OF DEPARTURE FROM AMSTERDAM 1-1-32 TILL 1-1-33
31-12-31
7-1-32
14-1
21
28
4-2
11
18
25
3-3
10
17
24
31
7-4
14
21
28
5-5
12
19
26
2-6
9
16
23
30
7-7
14
21
28
4-8
11
18
25
1-9
8
15
22
29
6-10
13
20
27
3-11
10
17
24
1-12
8
15
22
1 JAN 32
TILL
1 JAN. 33
AVERAGE
OF
52 TRIPS
EAST
BOUND
10½
DAYS
SCHEDULE ELEVEN DAYS
SUMMER SCHEDULE NINE DAYS
SCHEDULE TEN DAYS
BAD WEATHER
VERY BAD WEATHER.
◇ = FOKKER F.7 B THREE TITAN
○ = FOKKER F.18 THREE WASP.
◎ = FOKKER F.18 THREE WASP.
MAXIMUM, AGREED UPON WITH DUTCH POSTAL ADMINISTRATION: 12 DAYS

FIG. 5.


REGULARITY WEEKLY AIR MAIL SERVICE
BATAVIA - AMSTERDAM — K.L.M. AIRLINES.
WESTBOUND
NUMBER OF DAYS
1 2 3 4 5 6 7 8 9 10 11 12 13 14
DATES OF DEPARTURE FROM BATAVIA 1-1-32 TILL 1-1-33
1 JAN. 32 TILL 1 JAN. 33 AVERAGE OF 52 TRIPS WEST BOUND
9 8/10 DAYS
SCHEDULE ELEVEN DAYS
SUMMER SCHEDULE NINE DAYS
SCHEDULE TEN DAYS
◇ = FOKKER F 7 B THREE TITAN.
○ = FOKKER F 12 THREE WASP.
◎ = FOKKER F 18 THREE WASP.
PLANE SUNK AWAY ON WET GROUND.

MAXIMUM, AGREED UPON WITH DUTCH POSTAL ADMINISTRATION: 12 DAYS

FIG. 6.

AVERAGE REVENUE PER PRODUCED TON/KM.

From mail transport	D. fl.	2,420
,, passenger transport	,,	0,184
,, transport of extra luggage ...	,,	0,007
,, freight transport	,,	0,023
Total ...	D. fl.	2,634

COST PRICE PER PRODUCED TON/KM.: D. fl. 2,37 (inclusive of depreciation, insurance and all overhead expenses of the Amsterdam-Batavia route).

Commercial Ground Organisation

The K.L.M. has no personnel of its own stationed along the route. The agents charged with the promotion of its interests are selected according to the following method. In those countries where local air traffic already existed, these air companies, when such was feasible, were charged with the representation. In this way co-operation originated with the Imperial Airways in Egypt and Iraq, with Junkers Luftverkehr in Persia, and with various air companies in Europe, whilst in Netherlands India, Royal Netherland Indian Airways (K.N.I.L.M.), the sister company of the K.L.M. which operates air traffic in India, was appointed head agent for the whole of the Far East. In our East Indian Archipelago, this company has supported admirably the work of the K.L.M. The presence of an organisation like that of the Royal Netherland Indian Airways at the terminus of the air line Amsterdam-Batavia, has contributed not a little to the success of this service over a route of 9,000 miles. In countries where no air traffic existed, those persons or firms were appointed agents who had shown the greatest interest and active helpfulness in the first experimental flights. In various places these are Dutch firms; in many others, however, local enterprises or business men. The result is that the agencies of the K.L.M. are in the most varied hands, but thanks to the drawing up of very clear instructions, all these agencies do excellent work.

Organisation of Passenger and Goods Traffic

The considerations which led to the adoption of the principle of mixed transport have already been mentioned. As regards passenger traffic, the K.L.M. took the point of view that the daily stages flown ought to be as long as possible, with at most two intermediate landings and a final stop in places which guaranteed sufficient comfort for travellers and crew. The division of the daily stages as these are to-day was made with this object in view. At the same time, the K.L.M. made arrangements with hotels and rest-houses along the route, according to which passengers obtain food and lodging without paying for it. Later, the account is settled with the K.L.M., through the agents, at fixed prices. The result is, thus, that the traveller's hotel expenses are included in the price of his ticket and he does not need to worry about money exchange rates. Eventual " extras " are paid for by the commander and a settlement takes place later on in guilders or pounds. The agents along the route are informed by code telegram how many passengers are on board, so that they know how many rooms to engage and how many taxicabs must be waiting at the aerodrome. Moreover, the agents are informed how much loading capacity is available for their stations. Booking in eastwardly direction, as long as the machine has not started, is centred in Amsterdam, and from east to west, in Batavia. Afterwards requests have to be addressed to the commander. Detailed instructions regarding goods transport are supplied to all agents along the route. This is especially necessary,

as the transport of goods along the Indian route brings with it very peculiar complications.

Customs and other Formalities

The formalities required by the Customs are by no means slight. At nearly all ports they demand a manifest for goods discharged, one for goods taken on board and three for transit goods. Special permits are necessary for transit of gold in Persia and permission must be asked anew on each occasion. Iraq has a transit duty of 1/10 per cent. *ad valorem*, which must be regarded as very prohibitive, especially where it concerns the transit of gold, and in all cases makes the transport of valuable goods almost impossible. Formerly this transit duty amounted to as much as half per cent. Further, there is always a great demand for the numbers engraved on the revolvers on board. On landing in different ports in the same country, these useless control formalities are frequently repeated. Iraq further demands that the manifest for a packet which passes through Iraq in transit shall be stamped by the Customs at the port where it finally leaves the aeroplane, and sent back to the Customs at Baghdad. Formerly, things were still worse and they demanded the stamp of the Customs at the place of destination. For example, the K.L.M. carried a packet from London destined for Shanghai. At Alor Star it left the aeroplane, went by parcel post to Singapore and from there by boat to Shanghai. And if the Customs at Shanghai did not stamp the manifest and send it back to the Customs at Baghdad the K.L.M. was fined (f.i.) 150 rupees, whilst for the carriage of the packet it had received £1 2s. 4d. It is self-evident that with such regulations it is impossible to develop a transport traffic. The remarkable thing is that such regulations are made by countries which, as far as traffic is concerned, are more or less isolated from the outside world and which should most appreciate the fact that air line communications touch at their capitals.

Connections

The air line Amsterdam-Batavia should not be regarded solely as an express service between two parts of the realm of the Netherlands, but rather as an express service between Europe and Asia, and even, in view of the connections which it gives, between Asia and Africa and even Asia and the United States. The fact that the most obvious connection, that with Australia—only two days' journey or 15 hours' flight separates Netherlands India from the fifth continent—has not yet been brought about, is not due to any reserve on the part of Dutch air transport circles.

If one just studies the connection, then we see first of all that at the European terminus of the line, all the means of communication—in the first place the great West European air lines—run in connection, whilst an express service to America is also possible. If we consider the Indian terminus of the line, then we see connections by air with Semarang and Surabaya and connections by train from Alor Star with Penang and Singapore, whilst Batavia, Surabaya and Singapore form junctions from which one can proceed farther by boat to practically all the principal places in the Far East, such as to the chief towns of China, Japan and the Philippine Islands, whilst there are also several very good connections by boat to and from Australia. At Bangkok, one can travel further with the Air Orient to Saigon and shortly to Hanoi, Hongkong and Shanghai. At Karachi there is a connection with the mail line of British India, linking up Bombay and Madras. At Cairo there is the connection already mentioned of the Imperial Airways to Cape Town. Arrangements have already been made with various transport companies by which passengers can book through to their destinations.

Co-operation with Foreign Companies

When discussing the organisation of agencies, it was pointed out that co-operation was sought in many countries with existing air transport companies. At the present time three companies maintain air traffic between Europe and Asia: Imperial Airways, the Air Orient and the K.L.M. A very close co-operation has gradually been arrived at with Imperial Airways and the French company Air Orient, the chief principles of which are the following:—Uniform tariffs and conditions of transport, choice of travel schemes in mutual agreement in order to give the public the greatest possible advantage, and the adoption of the same standpoint in air transport problems abroad. Each of the three companies pursues its own ends, each of which forms a unity by itself. Nevertheless, there are many points where their interests can result in keen competition. When one considers, however, that every year about 300,000 passengers travel between Europe and Asia, it is clear that there is room enough for each of the three companies if all parties aim at a good understanding and comprehension of each other's needs.

The Future

And now we approach what might be called a picture of the future.

In the two years in which the Indian line has been operated, one can already see such considerable progress in the sphere of ground organisation—aerodromes, wireless, direction-finding, weather reports, lighting, hangars—as well as in the sphere of aeroplane construction and navigation, that there is no reason why expectations which to-day might appear fantastic should not be realised.

How do we see the future?

In the first place, an increase in the number of flying hours per day. This will become possible by an extension of the meteorological services, an increase in the hours during which the wireless stations function and by night-lighting of the aerodromes. On board of the machine, an increase of the crew to probably three pilots, two Marconists and one mechanic, six men, thus, instead of four.

It means also, however, increased comfort on board, more room, less noise and the existence of berths for resting.

In the second place, keeping pace with the increase in the number of flying hours per day, *an increase in the speed of the machines* will be forthcoming. This has always been the aim of the K.L.M. The F VIIb (1929-1930) had a cruising speed of 165 km. (100 miles); the F XII (1931), 185 km. (115 miles); the F XVIII (1932), 195 km. (122 miles); whilst the F XX, now in course of construction at the Fokker Works, shall have a cruising speed of 245 km. (155 miles) and the F XXXVI of 225 km. (140 miles).

In the third place, *an increase in the loading capacity of the machines*, in order to arrive at an increase in the express transport of passengers and goods. It is clear that an increase in the flying hours per day and an increase of speed will considerably shorten the journey from Amsterdam to Batavia, and the shorter the duration of the journey the more clearly the advantage of the rapid communication will appear (provided regularity and safety are maintained at the same time) the greater will be the demand. In addition to an increase of the mail there will also develop an increase in passenger and goods transport. The result will be steadily increasing receipts from transport, and this will again lead to a decrease in the contributions of the public to the air service Amsterdam-Batavia (first in the form of a reduced contribution from the Post Office to the K.L.M. and later in the form of reduced postage).

In the future, the journey from Amsterdam to Batavia, thanks to the increase of speed and longer daily stages, as sketched above, will prove possible in four days.

The traveller, who even now does not find the journey in nine or ten days at all fatiguing, thanks to the comfort on board and sufficient opportunity to rest, will, in the larger machines, be able to enjoy sufficiently his night's rest. The day journey will begin about two o'clock in the morning and last, with interruptions for tank-filling, till about five o'clock in the afternoon. The traveller can then repair to an hotel, get a wash, dine and rest, then stepping on board he can rest again. Also during the day there will be opportunity enough for resting, as indeed there is to-day.

There is no reason, therefore, to fear that the rapid journey in four days will prove a fatiguing experience.

Rapid communications by air between Amsterdam and Batavia is now established and in the two years of its existence has already shown considerable progress, technical, economical, and also as regards organisation.

It is now a question of making it more and more perfect. According as the transport increases and the ground service is improved, the machines will continually become larger and more rapid, whilst their equipment will always in greater degree answer the requirements for economic transport.

Those who took up the pioneers' work will not look in vain for the realisation of the aim they set themselves. The East may remain the East and the West the West—air transport will bring the two always closer and closer together.

In the air a great economic work is being achieved.

Discussion

The President extended most sincere thanks to Mr. Plesman for his paper. The Society, he said, appreciated very greatly the fact that so busy a man had found time to prepare and to come to England to deliver so comprehensive a paper, which the meeting had listened to with the greatest interest and enjoyment. He again congratulated Mr. Plesman upon the magnificent achievement of the Royal Dutch Air Lines, for which achievement he personally was so largely responsible. Although Mr. Plesman had commented that he had been addressing a technical audience and not an audience of future passengers, the President assured him that his statements had inspired the greatest confidence in the line under his control.

Lieut.-Colonel F. C. Shelmerdine (Director of Civil Aviation): He associated himself with the President's expression of appreciation of Mr. Plesman's very full account of the Amsterdam-Batavia weekly service, which account had been of the very greatest interest. Obviously, the subject was most interesting to aviation authorities of this country, for they were already operating over a portion of the route discussed—between Athens and Karachi—and hoped that before very long, when their projected extension to Australia was in operation, they would be operating over the whole of the remainder of the K.L.M. route eastwards. They looked forward, and he felt sure that they could do so confidently, to the closest co-operation between Imperial Airways and the K.L.M. in the operation of that extension in the near future. The route discussed in the paper was also of extreme interest to them because, as Mr. Plesman had so generously pointed out, the ground organisation over the greater part of it had been carried out by the British Government, in one part, the Government of British India in another, and, farther east, by the Malay States Government, and they were very glad to know that, so far as it went, it had proved satisfactory. It was appreciated, of course, that there were many ways in which it could be improved vastly, and in which it needed improvement, when money could be made available.

Colonel Shelmerdine was particularly interested in the statements made in the paper concerning the choice of the type of aircraft, because when he went to India in 1927 his first task was to organise an air route from Baluchistan, in the west, to Victoria Point (Burma). The route as far as Calcutta was obviously

one for land machines, but a multitude of people had given him varying advice with regard to the route beyond Calcutta. Some of them had said that it was impossible to use anything but flying boats, and others had said that it might be possible to operate with land machines. Unfortunately, the funds at his disposal were very limited, so that he could not organise the route for the use of both types of machine; it was impossible to provide aerodromes for land machines and at the same time seaplane bases with slipways and the various other requirements of seaplanes. Therefore, he had decided upon a land machine route, because it seemed impossible for the Government of India to say that a land machine could not proceed beyond Calcutta unless its wheels were changed for floats. He was very glad to hear Mr. Plesman say that the route eastward from Calcutta could be operated throughout the year by land machines.

Finally, Colonel Shelmerdine asked if Mr. Plesman was quite satisfied that, after leaving Bangkok, it was better at all seasons of the year to follow the east coast of Siam than to go back to the western coast, where there was much better organisation in the way of landing grounds and wireless facilities.

Colonel BARRETT-LENNARD (Imperial Airways, Ltd.): If any proof were needed that Mr. Plesman was a master of the subject to which he devoted his time and ability, the paper he had presented would provide convincing proof. On behalf of Imperial Airways, Ltd., Colonel Barrett-Lennard expressed thanks to Mr. Plesman for the very great contribution that he had made to our knowledge of commercial aviation. He agreed that political difficulties were not the least of the difficulties with which a commercial aviation undertaking had to deal, but apparently Mr. Plesman was a diplomat, and had managed to hang on in Persia, whereas Imperial Airways had been thrown out.

Reference was made in the paper to the relations between Imperial Airways and the K.L.M. In spite of that, Imperial Airways could not regard the K.L.M. as rivals, but preferred to regard the K.L.M. as co-operators; therefore, Imperial Airways had been glad to give the K.L.M. the assistance which it provided through its ground organisation, which existed from end to end of the route covered by Imperial Airways machines.

With regard to financial assistance, the K.L.M. obtained it through the Dutch Post Office, and, in view of the form of the agreement, the Dutch Post Office was interested in promoting the success of the K.L.M. Those were not the relations existing between the British Post Office and Imperial Airways. Imperial Airways received still greater support, however, from the Air Ministry, and gratefully acknowledged it; it was given on the principle that the British Government wished to extend as far as possible to the citizens of the Empire the advantages of this rapid and convenient form of communication.

There appeared to be nothing in the paper to suggest that Mr. Plesman approved of variable routes. Imperial Airways had found that not only was it very costly to vary the routes, but that in addition there were many inconveniences.

A good deal had been said about the Fokker machines employed by the K.L.M., but it would interest Mr. Plesman very much to look into the characteristics of the more modern planes used by Imperial Airways—the Handley Page four-engined "Hannibal" type, Short Bros. four-engined flying boat and the Armstrong-Siddeley four-engined monoplane. Probably he had done so already, but if he had not, he might do so with advantage, for he would find a great deal to attract him in those machines.

It had been shown quite lately that British designers of engines and aircraft could provide for quite high speeds. The difficulty was the use of the speed, and he did not quite understand how Mr. Plesman proposed to take advantage of it. Speed meant cost, in any form of transport, and it was not clear whether he would take it off his paying load, or in what other way he was going to take advantage of it.

Imperial Airways agreed that mixed cargo was absolutely essential to economic success. It was interesting to compare the traffic figures of Imperial Airways and the K.L.M. for 1932. They were as follows:—

K.L.M.

	kgs.
Mail	28,504
Passengers @ 100 kgs. ...	44,600
Freight	5,485

I.A.L.

Mail	64,762
Passengers @ 100 kgs. ...	243,000
Freight	38,460

The percentages of each class of cargo are as follows:—

K.L.M.

	%
Mail	36.27
Passengers	56.75
Freight	6.98

I.A.L.

Mail	18.70
Passengers	70.18
Freight	11.12

Combined figures are:—

Mail	21.95
Passengers	67.70
Freight	10.35

Commenting on the section of the paper headed "Relay System," Colonel Barrett-Lennard said he was in serious disagreement with Mr. Plesman in regard to the analogy drawn between an aeroplane and crew and a steamship and crew; he did not regard it as a true analogy. There was more than one objection to the proposal to use one crew throughout. A steamship crew had watches on and watches off, but the pilot of an aeroplane combined many functions. Not only was he the captain in charge of the whole machine, but was also navigator and was his own helmsman; in addition, he was chief engineer and also, in the case of the K.L.M. route, a sort of travelling traffic agent. Thus, he had a great deal to do, and possessed, or ought to possess, a good knowledge of the country over which he had to fly. To expect one man, with so many and such onerous duties, to fly day in and day out through the frosts and fogs of Europe, the terrible storms of the Eastern Mediterranean, the dust storms and heat of Iraq and Arabia, the monsoons of India and the fatiguing heat of the Far East, was to expect rather too much, and he would ask Mr. Plesman to reconsider that question. The pilots, both Dutch and English, were very fine fellows, and the aim should be to get the best, rather than the most, out of them.

Sir JOHN SIDDELEY (*Member of Council*): He had had the pleasure of knowing Mr. Plesman for many years, and felt sure that all who had heard the paper would have as much admiration as he had for Mr. Plesman's many-sided qualities. When one discussed civil aviation with Mr. Plesman, or with his chief engineer, Mr. Guilonard—whom Sir John had also known for many years—one felt quite certain that, in the hands of the K.L.M., at any rate, civil aviation had a great future. That impression must have been created upon all who had listened to the presentation of the paper. The information it contained served to show that successful civil aviation could be accomplished only by great organisation, very thorough and very complete, and if the paper had made that clear, and had done nothing else, its presentation was not one of the least services that

Mr. Plesman had rendered to civil aviation. The statement that the training of a good mechanic capable of accomplishing this type of work occupied five or six years, made it clear how thorough the training must be before civil aviation could even be considered as a practical proposition. Sir John added his testimony to the great service Mr. Plesman had rendered by his paper.

Mr. F. HANDLEY PAGE (*Fellow*): In this country particularly they appreciated his work because the Dutch Company operated, as did Imperial Airways, solely in the interests of civil aviation, *i.e.*, with the idea of providing a commercial service.

Mr. Handley Page was very interested to read in the paper that the F.XII machine came out rather too heavy. That difficulty had also been known in this country, he believed. But what had interested him still more was that the Dutch Company were able to reduce the weight afterwards. One means of doing this was to use electron for the petrol tanks and cowling, and also for the chairs. Its use for chairs had been discontinued owing to the corrosion which had occurred, but apparently its use for the petrol tanks and cowling was continued. He supposed these two latter items were not so important as the chairs for the passengers! However, he would be glad to hear what had been the experience, from the point of view of corrosion, of the use of electron for petrol tanks and cowling—whether the metal had resisted the effects of the different kinds of petrol used and the different climates. It would also be interesting to know how the Bakelite plywood used had withstood conditions in the tropics.

It would have been of particular interest if Mr. Plesman could have shown a picture of the Fokker F.XXXVI, which was to accommodate 16 passengers, and would cruise at 140 m.p.h. They were always very much more interested in what was to be used in the future than in the machines used in the past or those in use to-day. In the illustrations of the machines used so far there were shown seats for three or four passengers, and a crew of three or four people was carried, so that it seemed that the proportion of staff to passengers was rather high—unless, of course, one was accustomed to travelling in a Rolls-Royce car, sitting alone in the back, and having perhaps a chauffeur and a footman in the front. They could not regard that, however, as commercial transport. He hoped Mr. Plesman would show a picture of the new machine, in which this difficulty of the disproportionate allotment of seats would be overcome.

Mr. H. L. HALL (Chief Engineer, Imperial Airways, Ltd.): With regard to the decision as between the use of land planes and seaplanes, he gathered that seaplanes were not used because they involved greater costs of repair and maintenance than did land planes, but he would like to know whether the decision was based on actual costs of operating comparable types of land planes and seaplanes.

Whilst he admired American engines, he drew attention to Mr. Plesman's statement that, although they could be run for 400-500 hours between overhauls, they were allowed to run only 300 hours between overhauls on this route. He had heard that period of 300 hours mentioned in several quarters and had concluded that it represented the really safe time for American engines. They in this country had been getting from our engines for some considerable time up to 600 hours' running between overhauls, with the greatest reliability and very low cost, and are looking forward confidently to getting 1,000 hours' running between overhauls in the not too far distant future. There was much difference of opinion among authorities as to whether it was advisable to run engines for such long periods between overhauls, but in his experience, and looking at the matter from the point of view of costs as well as that of regularity of operation, there were very decided advantages in so doing, and they were of importance. For example, fewer spares were needed, and there was less expenditure on overhauls. It was his experience that, whether an engine was taken to pieces after

300 hours' or 600 hours' running, the inspectors and the men behind them would desire the expenditure of pretty well the same amount on the work and materials.

With regard to cylinder temperature indicators, he said that Imperial Airways had used them, but they were looking for a really good indicator. He was curious as to the accuracy and reliability of the type of temperature indicator which he had found was advocated for use with American engines, whereby one might have a switchbox to switch the current from thermo couples on three or four engines on to the one indicator. The switchbox might be the cause of a lot of trouble. No doubt, even with the immature instruments obtainable to-day, the K.L.M. had derived real benefit from their use, in the way of checking up the quality of fuel used—but he would pause to add that they obtained their fuel from the Shell organisation.

With regard to aircraft being struck by lightning, he had had the pleasure of collaborating with Mr. Guilonard on this subject and many others. Among the very few cases known wherein civil aircraft have been struck by lightning there was not a single instance of anyone being seriously hurt. Many are helping on this problem—the Signals Department of the Air Ministry, the N.P.L. and Messrs. Marconi's, and so on—to try to get down to the safest possible conditions for meeting storms in which lightning was likely to be encountered.

The remarks of Mr. Plesman with regard to inertia starters were in line with his own ideas; one could grind away at the crank for ten minutes and yet not get a start. As to the pistol starter, he did not think that if properly controlled it would ever damage the engines, but it was possible to run out of cartridges on a cold day without getting a start. At present he preferred the gas starter, which had the advantage that it would start an engine under all weather conditions and could be used for other purposes also, such as pumping up tyres and pumping petrol and particularly for providing motive power for emergency wireless.

With regard to the maintenance of height when one engine was out he considered that it was better to have three engines out of four running than two out of three; it was better still, of course, to have five out of six running than one out of three, but he agreed that the number of cases in which a second engine had failed in one flight were negligible.

As to propellers, his company were still in favour of wooden ones, mainly because of the great advantage in cost and weight. They are still using wooden propellers with great success on all their routes and they had experience with metal propellers in the Near East.

He said that he regarded the K.L.M. drift indicator as an outstanding example of reducing to the simplest possible terms a rather difficult scientific problem.

As to the experience concerning sickness amongst crews, he asked if that were entirely unconnected with the absence of ground engineers throughout the route.

The attainment of high speed flight presents no difficulty other than that of cost. It appears that the K.L.M. are going to considerably increase their speed on the Amsterdam-Batavia service, and it would be interesting to know whether the traffic receipts will offset the increased cost, or whether this cost is to be met from some other source. No doubt, in future, reduction of cost of operation and increased demand for high speed air transport from a public able to pay for it would satisfactorily solve this difficulty.

What the lecturer said about the extension of the time between overhauls of the aircraft from 500 to between 1,800 and 2,500 hours was most interesting. It would be equally interesting to learn how much overhauling is done at the end of each journey and how long the aircraft are out of service during other overhauls.

For some years past some British civil aircraft have considerably exceeded 1,000 hours between overhauls.

In conclusion, he expressed appreciation of the achievements of the K.L.M., who, by their operation of the route to the East, had unquestionably set another milestone on the path of progress in civil aviation.

Mr. HANDOVER (Traffic Manager of Imperial Airways): He was able to co-operate very closely with Mr. Martin, who is in charge of the operation of the Dutch East Indies service, by means of monthly meetings. Both companies were in agreement on a number of points, although on others, such as the captain acting as passenger agent, they agreed to differ. Imperial Airways prefer other means, as for instance, currency coupons. He agreed entirely with Mr. Plesman as to the separation of mail and passengers, and finally he paid a tribute to Mr. Plesman's courage in developing the long Amsterdam-Batavia route.

Capt. A. G. LAMPLUGH (British Aviation Insurance Company, Ltd., *Member of Council*): He would like to comment on three things. The first is the wisdom of carrying passengers in land aircraft over a sea crossing exceeding 250 miles, for while things are successful nothing much matters, but if by some mischance a land aircraft with passengers and mail does make a forced landing in the Mediterranean, he felt convinced that the weight of public opinion would be very decidedly against an air line using land aircraft for the service.

With a flying boat at least the company have done all they can to safeguard the passengers and mail, and with a land aircraft they have not done all they can.

Does Mr. Plesman feel satisfied with the weather reporting arrangements in the Near East? The general experience of pilots is that the weather reports are unsatisfactory and delayed, unless they happen to come as a forecast from Amsterdam or Cairo. He thought considerable improvement could be effected in this direction.

His third point is the question of the health of passengers, and he did not agree with Mr. Plesman that passengers suffer no fatigue. The lecturer has shown them that he habitually starts one hour before dawn, and he is proposing later on to start three hours before dawn. No passenger who has paid a considerable sum of money for his passage can reasonably fail to object to continuous rising at 3 a.m., particularly if he has interested himself in the amenities of any important town at which an overnight stop is made. In addition to this it must be remembered passengers are transported very rapidly from cold to hot climates, and *vice-versa*, and they have little chance of slow acclimatisation, such as they have on board ship.

Dr. BISSCHOP (Counsel to the Netherlands Legation in London): He was most interested in Mr. Plesman's remarks regarding the political factor as an obstacle threatening international air traffic. Although, as he points out, it is often asserted that air traffic knowing no frontiers will contribute to effect closer co-operation and a better understanding among nations—only too frequently that understanding is upset and air traffic considered a source of political wrangling and obstruction. Optimistically he expresses the hope that the political factor in air traffic is on its last legs.

It was unfortunate, when air traffic had to be internationally regulated the first principle recognised by the various nations was that every Power has complete and exclusive sovereignty over the air space above its territory. The word sovereignty has played havoc with international relations between the various nations on terra firma where political frontiers can be delineated, it is a calamity to extend so unfortunate an assumption of power to illimitable space in the sky. How far should it extend and effect its rules? Does it include the stratosphere or regions which human beings cannot penetrate except with artificial means of respiration?

The old adage of Roman law that a person was master over the property which he owns " usque ad coelum " did not go very far, because " coelum " in Roman eyes was a limited space hardly a mile from the earth and only extended to the building rights and the erection of plant on one's own property.

The only element with which the air can be compared is the sea. As much as the waters of the ocean cannot be partitioned and are free to all persons who want to make use of them for purposes of transport, so is the air free for mankind for all lawful purposes from breathing to transport and wireless transmission of human thoughts. How are sovereign powers to be exercised except by arbitrary means and the knowledge that no one can remain in the air for an unlimited period? Wireless activity should have convinced the nations of the artificiality of such sovereign powers.

Air has been wrongly treated on a par with inland waters which may be considered part and parcel of the surrounding country, like a lake, or a bay, or a fjord. It should from the beginning have been treated similarly to the wide expanse of water in the ocean where rules of navigation apply and the prohibition of its abuse by pollution with indissoluble remnants of oil, but where no troublesome activities of sovereign powers apply except for the fringe where the waters touch the shore of continents and the three-mile rule applies.

In the same way the freedom of the air is subject to rules of aviation and does not admit its abuse by aviators who use it for transportation of men and goods. Subject to proper safeguards it is free to everyone and subject to no national laws except for a similar fringe like the three-mile limit of the sea where the air is nearest to the earth.

Within such limit and for landing purposes national rules are laid down in accordance with international conventions. Above it the air is free and open for aviation irrespective of national aspirations or sovereign powers.

He knew that objectors to such theory always rely on military reasons and warlike preparations which render it necessary to take preventive measures against spying from the air.

Such reasons, however, are of a national character and may be classified—if necessary, which in some instances may be exaggerated—as prohibition of abuse of navigation for other purposes than transport in the same way as piracy is prohibited on the ocean. Neither warlike preparation nor even war conditions are acceptable reasons for extending an artificial division of continents in political nationalities to violate the freedom of the air, and if war became impossible by the recognition of such freedom mankind could only benefit to a larger extent than by the retention of a narrow-minded conception of air and air traffic.

He was afraid that Mr. Plesman's optimism of political factors in aviation being on their last legs will not be shared by every student of international relations between sovereign powers, but he agreed with him that it is the aviator who will be the powerful agent to break these enclosures down and remove all obstacles in the way of an international recognition of the freedom of the air.

Mr. W. A. Campbell (Technical Assistant, Directorate of Civil Aviation, London) (*communicated*): Mr. Plesman foresees an increase in the loading capacity of aircraft. This would result in the employment of larger machines. He also hints at more flying being carried out by night and would undoubtedly like to see better aerodromes, communications and meteorological facilities. To use the simile of the railway, the operators of air transport aircraft will require a better equipped " track." Is Mr. Plesman in a position to indicate what contribution his company propose to make towards the provision of such a " track " and to state what contribution they make at the moment?

Mr. Plesman puts his cost of production of one ton/km. at Dutch florins 2.37. What proportion of this charge goes towards the cost of the " track "? So far as we are aware landing and housing fees are the only " track " charges the

K.L.M. Company have to meet. Can he give their proportion in relation to the whole cost of operating the ton/km.?

Reply to Discussion

With regard to Colonel Shelmerdine's reference to travelling on the western coast after leaving Rangoon, last year the machines had followed the west coast and had made one landing at Victoria Point, but it was found that Victoria Point was too much enclosed, and since he had had permission to land at Kohlak advantage had been taken of the fact that when the monsoon came from the west against the hills, the sooner the machines were over the hills the sooner they were in a better climate. At a later period the aerodrome at Bangkok was soft, and then the machines followed the west coast; the monsoons were then on the eastern side of the mountains, and the machines then jumped across the mountains at the nearest point to Kohlak. Although there had been some difficulty at Victoria Point, it was possible that later the machines might follow the western coast, when a few alterations could be made, but with the existing organisation it was considered that the route now followed was the better.

As to variable routes, it was not difficult for the K.L.M. to change from one route to another, because there were only a few cases of spare parts en route, and no personnel. He had already explained the reason for the system adopted. The K.L.M. were really poor. That was a reason also why they could not buy big seaplanes. As to whether there had been a comparison of the two types of machine, he said they had only the comparison between the small seaplane and the small landplane; they knew what the relative expenses were in those cases, and therefore, they did not adopt seaplanes. He had considered, of course, various types and makes of machines before those used were decided upon, but he could not mention in the paper all the details to which he had given consideration, because he had had to condense the paper as much as possible.

Commenting upon Colonel Barrett-Lennard's comparison of the traffic figures for Imperial Airways and the K.L.M., Mr. Plesman pointed out that in order to get a true picture it would be necessary to compare also the expenditure of each organisation. That would involve complications.

As to the criticism of his analogy between aircraft and crew and steamship and crew, he said that the crew of each aeroplane numbered four, and the men really worked in shifts. One pilot was at the wheel for only two hours, when he was relieved by another pilot. When there were no passengers, the relieved pilot could rest in one of the long chairs provided for passengers; when all the long chairs were occupied by passengers, however, the relieved pilot could rest in a smaller chair, two of which were carried for the accommodation of passengers travelling short distances intermediately. He urged that planes should be constructed with the idea that they would carry fairly big crews, who would work in shifts. In the future, large planes would carry three pilots and two wireless operators.

As to the effect of the journey upon physique, he recalled the statement in the paper that a doctor had travelled along the whole route and had examined the pilots each day. Before the commencement of the journey he had examined each one, and had given for each man a figure representing his physical condition; whenever he had examined them subsequently they were given figures on that standard, and in each case the figure was higher when the journey was completed than when it had commenced. There was definite proof, therefore, that the crews were not subjected to undue strain.

He thanked Sir John Siddeley for his kind remarks, which were highly appreciated both by Mr. Guilonard and himself.

With regard to the F.XII, it was not really too heavy; indeed, it was not up to the maximum weight, but the company had asked the Government for

permission to make some changes in the plane so that they could carry an extra 200 kg. The bakelite plywood was very good material for the tropics. It must be glued very carefully, of course; it was in the form of very thin plates, and it could be used on the wings only in those parts where the stress was not great.

He regretted that there were no pictures of the F.XXXVI yet available. The machine would carry 16 passengers. In the middle there would be two cabins, each for eight passengers. Each cabin was again divided into two, there being four passengers in each division. In each cabin there were four berths—two high and two low—and eight chairs, so that there were 16 seats, and eight sleeping berths altogether. The supposition was that there would be eight passengers travelling over the full route and eight travelling short stages en route. Arrangements were being worked out, in collaboration with the interior decorators, so that 16 beds could be provided if necessary.

Discussing Mr. Handley Page's reference to the proportion of crew to passengers, he pointed out that the service was a mail service as well as one providing passenger accommodation, so that a crew of four was necessary. The minimum number of crew was two—two pilots or a pilot and a wireless operator—but if two other men were not carried on the machine it would be necessary to station personnel en route; it would be necessary to have about 20 or 24 expert mechanics, but the company had not the mechanics available, and therefore, it was better to carry the necessary men on the machines. Later on, perhaps, when the frequency of the service was greater than once per week, it would pay to establish personnel on the ground. When it was possible, with machines carrying 16 passengers, to have a smaller proportion of crew, and to have more men on the ground, that would be done.

He agreed with Mr. Hall that in the future engines would be run for 1,000 hours between overhauls. Indeed, the Wasp engines had run in Europe for nearly 500 hours between overhauls, and the overhauls were not very expensive. When one was quite certain that each part would stand up to its work it was better to leave the engine closed, but when one realised that a piston pin, for instance, might fail within 1,000 hours—and its failure would affect the whole engine—it was wise to overhaul at periods shorter than 1,000 hours. Although a period of 500 hours could be adopted in Europe, he did not like to adopt it on the Eastern route, because that was a difficult route. When one was flying from Calcutta across the Bay of Bengal, without touching Chittagong, direct to Akyab, and one knew that there were sharks below, one felt it was better to overhaul at periods of 300 hours rather than 500 hours.

With regard to temperature indicators, he agreed with Mr. Hall. He also agreed with Mr. Hall's remarks concerning four-engined machines, and said that the F.XXXVI would have four engines.

It was true, as Mr. Handley Page had said, that it was better to talk of the future than of what had been done already, when addressing members of the Royal Aeronautical Society, and he would be glad to arrange with Imperial Airways about a talk on the needs of the future.

Reply to Capt. Lamplugh.—1. The problem "seaplane or landplane" has decidedly been solved in favour of the landplane. For years people wanted to use hydroplanes in order to avoid the building of aerodromes, supposing that they could exploitate hydroplane services along the sea coast or rivers in that way. All those projects are vanishing one after the other. I think that Captain Lamplugh, with his very great experience on this subject, can recollect many cases such as I have pointed out above. This is of course raising a very wide field of technical problems. It is known that in the small hydroplanes and in those of moderate size, the empty weight of the machine, plus equipment, is much higher than of land aircraft. This is changing when the aircraft becomes bigger. It will be possible to build seaplanes of over 2,000 h.p. which will be—

as regards the empty weight—nearly equal to the landplane. It is possible to give now in the aeroplane more weight to reserve power in the engines and in the amount of petrol. If a three-engined machine can fly with absolute safety on two engines, then a landplane is safe enough to cross a stretch of water. I think there have been more accidents with hydroplanes over sea with fatal results than with land machines. The public opinion does not decide in these matters. It is a technical problem, and the public opinion is capricious and depends very much on the attitude the press takes with the competitors. We have to take the problem as a whole; the advantage to fly with the same aircraft from Amsterdam to Batavia is so big, that the operator must take the responsibility to fly over stretches of water if he feels technically justified to do so. To fly on two engines over water is the easiest case, as the ceiling of the plane is so much higher and you have always reserve power. To fly on two engines over mountainous country is much more dangerous, as you have to fly on a certain altitude already in bumpy weather or perhaps bad visibility.

2. About the meteorological reports, I have already said in the paper that they are sufficient at present but that of course they have to be improved still very much.

3. The shipping people in Holland are contemplating an airship line from Barcelona, via Aden, to Batavia in five or six days. It is logical that when aeroplanes will have to compete with such a scheme they will have also to do the whole stretch in that time. The rapid change of climate seems to be only theoretically of such great importance, as on all the record flights no complaints in this respect were made. Remains the fact of getting up early in the morning. This will be facilitated very much by special arrangements, as in the aeroplane there will be berths ready, so that the passengers will practically only have to change their beds. When the machine is absolutely ready to start, the passengers are called and find everything ready for them in the plane. How this system will work is not yet known. There will perhaps be people, like the interrogator, who will have some objections, but they can only judge when the system is put into practice.

Reply to Dr. Bisschop.—It is indeed highly desirable that—as Dr. Bisschop argues—by international co-operation and regulation, more freedom is granted to civil aviation; this could be done in the most efficient way by modifying the Article 15 of the Convention of 1919 in such a sense that the Government may refuse an authorisation to fly over their territory only on reasonable grounds, and that only reasonable conditions may be attached to such an authorisation if it is granted.

It seems that it is not possible to change in the present circumstances the principle of sovereignty laid down in Article I of the Convention; this principle has become customary during the years of war; besides, by Article 2, each State undertakes in time of peace to accord freedom of passage to the aircraft of the other contracting States. A parallel with the open sea cannot be drawn in all respects, as the relations between maritime navigation and the riparian States differ from those between air navigation and the underlying areas. Complete freedom, if only from the fact that measures concerning public security and health could not be enforced, would bring the States into an untenable position. As Dr. Bisschop rightly says, a compromise is effected by admitting the desirability of a territorial zone being subject to the authority of the underlying States; he draws there a parallel with the maritime belt. On the other side it may be said that whereas the territorial waters may be considered as a protective area, the law of gravity prevents the aerial zone from exercising any corresponding function. Moreover, certain "droits de conservation" should be allotted to the underlying States even as regards the free air space in any case. And also there immediately the question arises, difficult to solve, to what height should that zone extend and from where should that height be measured? I

am therefore afraid that the idea of a territorial air zone—although being an excellent compromise—cannot be put into practical effect.

Among the members of the Air Convention there has grown during the last years a tendency to accord more freedom. In this connection attention is drawn to the new wording of Article 15 by which the necessity of previous permission is not explicitly required, and also to the recommendation adopted by the C.I.N.A. in June, 1929, that the States shall not refuse an authorisation otherwise than upon reasonable grounds. Also in Geneva various recommendations of the same tendency have been adopted. Of course it will still take some time before this idea will be applied generally in practice; on the other hand it is already a favourable sign that the States concerned recognise that more freedom is desired. The more in the various countries civil aviation will grow and the question of reciprocity will come to the foreground, the more it will be proved necessary to accord—in own interest—the freedom of passage.

Reply to Mr. W. A. Campbell, Air Ministry, London.—Mr. Campbell is pointing out rightly that the air traffic companies are paying landing and housing fees and that these must be sufficient for the operation of airports during daytime. When taking into consideration the landing and housing fees in the different countries, it appears that Croydon has in Europe the highest tariffs. It must be admitted that the ground organisation at Croydon is one of the best, although the same cannot be said of the aerodrome service.

It will be known to Mr. Campbell that many aerodromes have special tariffs for night landing arrangements and it is supposed that these tariffs will cover in the end the expenditure for night landing equipment.

Of course the K.L.M. will contribute to the expenditure of the ground organisation just like other companies and the Governments will set up such an organisation, knowing that when there is enough air traffic, they will come at their costs, if only the building and exploitation of the necessary equipment is made on an economical base.

I suppose that Mr. Campbell will not charge the pioneer companies heavier than those which will follow later on. There must be one international tariff which concurs with Article 24 of the Convention of 1929.

The landing and housing fees are, of course, only a small portion of the total cost price, just as you will find in every product, like the making of cars, automobiles, engines, etc., where the rent of the building and the expenditure for light, water, etc., forms only a very small fraction of the cost price in general. If Mr. Campbell should be of the opinion that this item could make out a greater proportion of the cost price, I am afraid that this is perhaps for the future, but does not seem practicable now.

We made a thorough investigation into this matter and our estimate at present is that the " track " charges come to f.0.19^6, the cost of one ton/km. coming to f.0.37. While considering this amount of f.0.19^6, please take into consideration that not only the landing and housing fees represent the " track " charges. I regret, however, not being able to give the exact amount of landing and housing fees separately, as we have no further specification of the " track " charges on the India line.

If the restrictions, made by certain Governments against the development of aviation, have been eliminated, the civil aviation will have developed as widely as can be expected, then the exploitation of ground facilities, night landing arrangements, etc., will show to the Governments the same profits or losses as is now the case with shipping facilities, etc.

I have found that constructors and users of electron have received a wrong impression of the information given in the lecture, *re* the construction of chairs made of electron for the Amsterdam-Batavia service and the results obtained with same.

In order to avoid misunderstandings as regards our opinion about the suitability of electron as a material for aircraft construction, I would like to state that this material has very definite advantages owing to its lightness relative to strength, and actually different parts of the aeroplanes in use in our company, such as engine cowlings and important constructional details of the undercarriages, wheels and brakes, are made of this light alloy, and have given complete satisfaction.

The difficulties with the electron chairs, mentioned in the lecture, were mainly caused by lack of experience in manufacture, and further by the condition that we wanted to use the material for decorative purposes without any protective paint.

Colonel the MASTER OF SEMPILL (*Past-President of the Society*): On behalf of all the members of the Royal Aeronautical Society and, in fact, all interested in aviation in this country, he considered it a privilege to be allowed to propose a very cordial vote of thanks to Mr. Plesman. They were all especially grateful to him for his exceedingly interesting and detailed paper containing a complete account of a very great enterprise for the inception and carrying into effect of which we note he has been primarily responsible. Mr. Plesman's knowledge of the English language was in itself the envy and admiration of his hearers, and everyone interested in air transport would look forward in the future to an even closer collaboration with the Dutch interests. It is well that the audience should appreciate that not only has Mr. Plesman been to great pains to prepare and profusely illustrate this paper, but he has brought with him to-night the Air Superintendent and the Chief Engineer of the Royal Dutch Air Lines in order that any question that may be asked can be answered directly by these officials of his company. This in itself is a great compliment to the Society and is yet another indication—not that any is needed—of the thorough way in which their Dutch friends tackle these matters.

SURGING IN HELICAL VALVE SPRINGS

BY

J. DICK, B.Sc.

The high-speed internal combustion engine presents many problems arising from dynamic effects. Amongst these is the phenomenon known as " surging " in the helical springs used for the operation of the valves.

If a helical spring is held at both ends, any disturbance in the spring passes up and down as a wave, being reflected at each end in turn. This to and fro movement continues until it is damped out by friction and air resistance. With most springs the speed of propagation of the disturbance is considerable and only a confused flutter of the coils is apparent to an observer. A disturbance of this type is caused by any movement of the end of the spring. The more abrupt the movement of the end, the more pronounced will the disturbance be. An instance of the type of movement producing a pronounced surge is that due to impact between the tappet and the valve when the valve commences to open.

If an impulse be given to one end of a spring, and a similar impulse is given to the same end at some instant when the disturbance caused by the first impulse returns to that end, the effects are additive, and the intensity of the resulting disturbance will be greater than that due to the single impulse. A succession of impulses, applied at the correct instants, will cause a disturbance of considerable intensity. This explains why " surging " in engine valve springs becomes pronounced at certain " synchronous " speeds. Swan and Savage* found that engine speeds which were small submultiples of the frequency of vibration of the spring due to its own inertia, were effective as " synchronous " speeds.

One of the results of the disturbance is a local change in pitch, which means a local change in stress. Surging in valve springs thus leads to increased stresses and thereby contributes to spring fractures.

A second effect is that the load required to compress a spring to a given length changes if surge is present. The effective load at any instant is determined by the extension or compression of the coil at the working end of the spring. With a severe surge the changes in effective load may be sufficient to interfere with the normal operation of the valve, causing " valve bounce " and impairing the efficiency of the engine at the speeds at which it occurs.

The phenomenon of surging in springs has been known for some time, and its effect in increasing the stresses was examined experimentally by Swan and Savage. Using a stroboscopic apparatus, they measured the deflections of different coils in springs working at the synchronous speeds at which the surging occurred. It was found that the range of stress could be increased by the surging by as much as 40 per cent. of the range estimated from the extension and compression under working conditions if no surge occurs.

The following pages offer a theoretical treatment of the distribution of surge stresses, not only in uniform springs, but also in tapered and barrel-shaped springs, with suggestions for methods of minimising the effect of these stresses.

* " The Surging of Engine Valve Springs." Department of Scientific and Industrial Research, Engineering Special Report No. 10.

The Speed of Propagation of the Surge Wave

A disturbance travelling to and fro in a spring has, at any point, a definite speed of propagation which can be determined from the spring dimensions at the point. With a uniform spring a general form of expressing this is as a speed of propagation along the axis of the spring in terms of the length, the rate, and the mass of the spring. This is

$$v_s = l\,(Fg/W)^{\frac{1}{2}} \quad . \quad . \quad \text{(See Appendix equation 1)}$$

where v_s = speed of propagation of the disturbance along the axis of the spring in inches per second.

l = length of spring in inches.

F = rate of spring in lbs. per inch deflection.

g = acceleration due to gravity in inches per second per second.

W = mass of spring in lbs.

It should be noted that to obtain the exact value, W is the mass of the effective coils in the spring, and l is the length measured over the effective coils.

A more fundamental form of expressing the speed of propagation is required for considering effects in non-uniform springs, and is obtained by expressing as a speed along the axis of the wire instead of along the axis of the spring. This expression is

$$v_w = (d/R)\,(Ng/8\rho)^{\frac{1}{2}} \quad \text{(See Appendix equation 3)}$$

where v_w = speed of propagation along the axis of the wire in inches per sec.

d = diameter of wire in inches.

R = radius of curvature of wire in inches (the mean coil radius).

N = modulus of rigidity of material in lbs. per square inch.

g = acceleration due to gravity in inches per second per second.

ρ = density of material in lbs. per cubic inch.

The Frequency of Vibration of the Spring

The frequency of vibration of the spring, or the number of times a disturbance travels twice the length of the spring in one minute, can be estimated from the spring dimensions. For a uniform spring a convenient approximation is

$$n = 588\,(F/W)^{\frac{1}{2}} \quad . \quad \text{(See Appendix equation 4)}^*$$

where n = number of vibrations of the spring per minute.

F = rate of spring in lbs. per inch.

W = mass of spring in lbs.

It should be noted that for the true frequency W is the mass of the effective coils in the spring. This is difficult to estimate and changes to some degree with the extension and compression of the spring. If W is taken as the mass of the complete spring the true frequency is a little higher than that given by the above formula.

The formula gives also a good approximation for the frequency of tapered and barrel-shaped springs.

The Characteristics of a Disturbance

A disturbance in a spring implies three things. These are:—

(1) The speed of propagation of the disturbance along the spring.

(2) The speed of movement of the wire in the disturbed part.

(3) The local change in extension or compression in the disturbed part.

* See also "High-Speed Internal-Combustion Engines, 1931," by H. R. Ricardo; and "Investigation of the Fracture of Exhaust Springs," Aeronautical Research Committee, R. & M., Series No. 241.

No matter what the initial load on the spring may be, for a single disturbance these characteristics have the following relationship

$$e = -V/v_{so} \quad . \quad . \quad \text{(See Appendix equation 5)}$$

where e = local change in extension or compression of the coil expressed as a unital strain.

V = speed of wire movement.

v_{so} = speed of propagation of a disturbance, measured along the axis of the spring, with no load on the spring.

If the movement of the wire is in the same direction as that in which the disturbance is being propagated, the strain causes a local decrease in pitch. If the movement of the wire is in the opposite direction to that in which the disturbance is being propagated, the strain causes a local increase in pitch.

The above relationship can also be expressed in the following form:—

strain energy per unit length due to the change in strain caused by the disturbance = kinetic energy per unit length due to the disturbance. (See Appendix equation 10)

If at any point in a disturbed spring, the wire movement and the change of strain do not have the above relationship, then two disturbances which are being propagated in opposite directions are passing each other at that point. Should the strain be greater than that corresponding to the speed of wire movement, then similar disturbances are passing each other. In the case of zero wire speed this gives a node. Should the strain be less than that corresponding to the speed of wire movement, then dissimilar disturbances are passing each other at that point.

When a disturbance is being reflected at the end of a spring the speed of wire movement is zero, so the effect corresponds to the passing of two similar disturbances. From this it follows that unless the coils close, the strain is doubled for the instant. This is one of the most important points in the discussion. When a single disturbance is passing up and down a uniform spring the strain in the end coil during perfect reflection of the disturbance is double the strain caused by the same disturbance in any other coil. This means that with the single disturbance the change in stress in the end coils is double that in the other coils.

If a succession of disturbances be started in the same spring, each disturbance and its effects can be considered separately and the resultant effect at any instant can be obtained by summing the effects of the different disturbances at that instant. The effect of any end movement of a spring can thus be estimated, either by graphical or algebraic means. In doing this it is convenient to neglect damping and distortion of the waves during reflection.

The Effect of Continued Periodic Motion of the End of a Spring

The type of end movement of most direct interest is some form of periodic motion. In the majority of cases such a motion can be shown to consist of a sum of simple harmonic motions, having a fundamental and harmonics of various amplitudes. In the Appendix to this paper the effects of simple harmonic motions of various frequencies have been analysed.

From that analysis it can be seen that with a simple harmonic motion applied to the end of a spring " building-up " of the surge cannot occur until the frequency of the simple harmonic motion is equal to or greater than the frequency of the vibration in the spring. This is of interest in indicating that it is the " localised " surge that lends itself most readily to resonance.

The Resonance of Surge Effects in the Operation of Valve Springs

If it be accepted that the parts of the end movement giving localised surge effects are of most importance in the study of surging, a little consideration will show that in valve operation pronounced localised effects will be produced by the points of maximum curvature on the cam-displacement diagram. These occur at opening and closing of the valve, where, if clearance between the valve and tappet is permitted, the curvature is theoretically infinite. Both curvatures are of the same sign, so they produce similar effects. The disturbances induced lead to a local decrease in pitch or a local compression. From this it might be expected that when surging occurs in valve springs, the pronounced part of the surge will be compressive, and the effect on the range of stress estimated from the normal extension and compression of the spring will be to increase the maximum stress with surging rather than to decrease the minimum stress. This was confirmed by the measurements carried out by Swan and Savage.

The full conditions of resonance of the various harmonics are complex, so it is proposed to review only the simplest case of resonance of the fundamental or the single vibration.

Over any two successive cycles, the worst surge effects depend mainly on the time-relationship of the following points:—

(1) Opening in the first cycle.
(2) Closing in the first cycle.
(3) Opening in the second cycle.
(4) Closing in the second cycle.

Resonance may occur initially between 1 and 2 and between 3 and 4, but the cumulative effect is not likely to be great until there is resonance between the cycles; that is, until the camshaft speed is an exact submultiple of the frequency of the vibration in the spring. When this occurs, there will be resonance between 1 and 2 and between 3 and 4.

A greater effect will be produced at the synchronous speeds where there is also resonance between 1 and 2 and hence between 3 and 4 and between 1 and 4. An alteration in valve clearance alters the time relationship in the latter case, but does not affect the time relationship between the cycles. Evidence of this was obtained by the measurements carried out by Swan and Savage, which showed that altering the clearance did not affect the synchronous speeds, but caused considerable changes in the amplitudes of movement.

The Points of Maximum Stress

The fundamental surge vibration is a single wave travelling from end to end. The change in unital strain caused by the wave is

$$V/v_{so} \quad . \quad . \quad \text{(See Appendix equation 5)}$$

where V = speed of wire measurement.

v_{so} = speed of propagation of a disturbance, measured along the axis of the spring, with no load on the spring.

It has been pointed out that, with perfect reflection of this disturbance at the ends, the strain has double the value given above. This means that, in practice, with a single disturbance the change in stress in the end coils may be double that in the other coils.

The second harmonic consists of two waves travelling from end to end with a phase difference corresponding to the length of the spring. If the speed of wire movement is V, the change in unital strain caused by each wave is V/v_{so}, except during perfect reflection at the ends, when the change in strain has double that value. The waves pass each other at the mid-point of the length, giving a node in which the maximum strain is the sum of the two dis-

turbance strains and is thus the same as the strain at the ends during perfect reflection. In this case the maximum node stress at the mid-point and the maximum reflection stress at the ends are equal.

The third harmonic consists of three waves having a phase difference corresponding to two-thirds of the length of the spring. The nodes are at one-third of the length from each end. If the speed of wire movement is the same for each disturbance the maximum node stresses and the maximum stresses during perfect reflection at the ends are equal.

In general, apart from the "stationary" points at the ends, the number of nodes is one less than the number of the harmonic, and in all cases, assuming perfect reflection at the ends, there is no node more highly stressed than the end coils. Since these have the maximum stress with every harmonic, it is apparent that the end coils are subjected to more severe conditions of stressing than any other point in the spring. In practice, fractures due to surging invariably occur in the coil about one pitch distant from the end.

Swan and Savage found that the fundamental or simple vibration was the most detrimental to the life of the spring, and they recorded that the amount of movement was greatest in the simple cases. The reason for this is that with the higher harmonics, provided the order of camshaft speed is the same, each vibration receives fewer impulses per cycle of the cam.

If it is accepted that the higher the harmonic the smaller the amplitude, then the point that is next to the end in degree of stressing is the mid-point, which forms a node for the even harmonics. Next come the points at one-third of the length from each end, which form nodes for the third, sixth, ninth, etc., harmonics.

The Distribution of Surge Stresses in Non-uniform Springs

If an impulse giving a speed of wire movement V is applied to the end of a spring, the change in stress in lbs. per square inch due to the disturbances is

$$V\,(2N\rho/g)^{\frac{1}{2}} \quad . \quad . \quad \text{(See Appendix equation 6)}$$

where N = modulus of rigidity of material in lbs. per square inch.

ρ = density of material in lbs. per cubic inch.

g = acceleration due to gravity in inches per second per second.

The above formula was deduced for a uniform spring and it will be noticed that the change in stress is a function of the material and the speed of the disturbing effect and is independent of the dimensions of the spring assuming that the end coils do not close during the application of the impulse.

With springs that are not uniform along the length the above formula still holds for the end at which the impulse is applied. If the disturbance travels twice the length of the spring without loss then during perfect reflection at the same end the stress has double the value given above and can be written

$$q_1 = 2C_1V \quad . \quad . \quad . \quad . \quad . \quad . \quad (a)$$

where $C_1 = (2N\rho/g)^{\frac{1}{2}}$ and is a constant for the material.

The surge stress at any other point can now be considered.

It has been pointed out that in considering the propagation of a disturbance in a non-uniform spring it is convenient to express the speed of propagation as a speed along the axis of the wire instead of along the axis of the spring. This gives a more fundamental expression.

The speed of propagation of a disturbance along the axis of the wire is

$$v_w = (d/R)\,(Ng/8\rho)^{\frac{1}{2}} \quad . \quad \text{(See Appendix equation 3)}$$

where v_w = speed of propagation of disturbance along the axis of the wire in inches per second.

d = diameter of wire in inches.

R = radius of curvature of wire in inches (the mean coil radius).

N = modulus of rigidity of material in lbs. per square inch.

g = acceleration due to gravity in inches per second per second.

ρ = density of material in lbs. per cubic inch.

The length of wire affected by a given disturbance is, at any instant, proportional to v_w, so assuming that no losses occur the disturbance energy per unit length of wire is proportional to $1/v_w$.

The volume of material per unit length of wire is proportional to the cross-sectional area, so the disturbance energy per unit volume of wire is proportional to $1/(v_w \times$ cross-sectional area).

In the torsion of bars, the strain energy per unit volume is proportional to the square of the maximum stress, so if q is the change in maximum stress due to disturbance $q^2 \propto 1/(v_w \times$ cross-sectional area).

The cross-sectional area is proportional to d^2, and for a given material v_w is proportional to d/R.

Substituting these, $q^2 \propto R/d^3$, that is, $q \propto (R/d^3)^{\frac{1}{2}}$ $(d_1^3/d_2^3)^{\frac{1}{2}}$.

If the dimensions at the working end of the spring are R_1 and d_1 and the stress during perfect reflection of a disturbance at that end is, from equation (a)

$$q_1 = 2C_1V,$$

then the stress due to the same disturbance at any point away from the ends is

$$q = C_1V(Rd_1^3/R_1d^3)^{\frac{1}{2}}$$

where R and d are the dimensions at the point under consideration.

If the dimensions at the fixed end of the spring are R_2 and d_2 the stress during reflection is

$$q_2 = 2C_1V\{(R_2/R_1)(d_1^3/d_2^3)\}^{\frac{1}{2}}$$

These formulæ can now be used in considering stress distributions in particular cases.

(*a*) *Tapered Springs with the Smaller End as Working End*

If the springs are of uniform wire throughout, the following stresses occur due to the surge:—

The maximum stress q_1 at the smaller end $= 2C_1V$.

The maximum stress at any point clear of the ends $= C_1V(R/R_1)^{\frac{1}{2}}$.

The maximum stress q_2 at the larger end $= 2C_1V(R_2/R_1)^{\frac{1}{2}}$.

With a uniform spring the corresponding stresses would be

$$2C_1V;\ C_1V;\text{ and } 2C_1V.$$

Since R_2 and R are both greater than R_1 and C_1V is constant it can be seen that the effect of tapering the coils is to increase the surge stresses in all parts of the spring away from the working end.

(*b*) *Springs in which the End Coils are of the Same Diameter, Smaller than the Diameter in the Rest of the Spring*

If the springs are of uniform wire throughout, the following stresses occur due to the surge:—

The maximum stress q_1 at the ends $= 2C_1V$.

The maximum stress at any point clear of the ends $= C_1V(R/R_1)^{\frac{1}{2}}$.

Since R is greater than R_1 the effect here is to give a surge stress at points away from the ends higher than the corresponding stress in a uniform spring, but the stress may still be lower than the stress in the end coils due to the same surge. This suggests the possibility of obtaining an economic design on the following lines:—

If the stress due to the axial load in the spring is C_2R where R is the mean coil radius at the point under consideration, then the following maximum stresses occur:—

(1) At the ends, the maximum stress $= C_2R_1 + 2C_1V$.

(2) Away from the ends, the maximum stress $= C_2R + C_1V(R/R_1)^{\frac{1}{2}}$.

For economic design these are equal.

$$\therefore C_2R_1 + 2C_1V = C_2R + C_1V(R/R_1)^{\frac{1}{2}}. \quad . \quad . \quad . \quad (b)$$

Swan and Savage found that in some cases the surging increased the range of stress in the end coils by 40 per cent. of the value estimated from the changes in length of the spring when working.

Taking 30 per cent. as the average change in stress with surging, then

$$2C_1V = (3/10)\ C_2R_1.$$

On substituting for C_1V in equation (*b*) and simplifying

$$R/R_1 + (3/20)\ (R/R_1)^3 = 13/10.$$

From this equation R/R_1 is approximately 1.14, so by making the diameter of the end coils about 16 per cent. less than the diameter of the remaining coils in the spring, the design is more economic than if the spring were uniform right to the ends.

It should be pointed out here that this does not reduce the surge effect in the end coils, but equalises the stresses throughout by reducing the stress in the end coils due to axial loading and increasing the surge stress in the coils away from the ends.

The Effect of Different Spring Rates

The frequency of a spring, in vibrations per minute, is

$$588\sqrt{\text{(rate of spring in lbs. per inch)/(mass of spring in lbs.)}}$$

It is apparent that, with springs of the same mass, a higher rate means a higher frequency. This gives:—

(1) A smaller period for the spring vibration.

(2) A greater number of "synchronous" speeds at which surge occurs.

The smaller period means that there is less chance of localisation of surge effects, and it has been indicated already that localisation of the surge facilitates resonance. The greater number of vibrations per cam cycle means that damping has more chance to be effective. To offset these, the greater number of synchronous speeds means more persistent surging in practice. It is obvious that, in considering surging, the best stiffness to choose will vary considerably with cam design and damping conditions. Practical comparison of effects is difficult, since springs of different frequencies cannot be used to do the same work under the same stress conditions. For a given maximum load and maximum stress, and a given movement, the stiffer the spring the greater is the range of load and the greater the range of stress. It is evident that this consideration is of greater importance than the factors affecting surging.

It is of interest to note that springs of the same rate which have the same stress with a given load have also the same surge frequency. This is evident from consideration of strain energy. For a given load, the strain energy per unit volume and the total strain energy are constant from one spring to another. From this it follows that the volume of material is the same in each case. Hence, provided the springs are of the same material, the ratio

$$\text{(rate of spring)}/\text{(mass of spring)}$$

is the same, which means that the springs have the same frequency of vibration.

Factors in the Spring affecting Damping, Reflection, and Resonance of Surge Waves

When a disturbance is moving along a spring, the disturbance energy per unit length of wire is

$$(\rho/g)\ (\pi/4)\ d^2V \quad . \quad \text{(See Appendix equation 8)}$$

where ρ = density of material in lbs. per cubic inch.

g = acceleration due to gravity in inches per second per second.

d = diameter of wire in inches.

V = speed of wire movement in inches per second.

Since $\rho (d^2/g)$ is small, and V, the speed of wire movement, is not large, it will be seen that the energy per unit length of wire is small, so a small change in damping must have considerable influence on the persistence of the surge. This is one reason why surge effects vary so much from spring to spring. The most effective damping comes from a small amount of rubbing friction, and this occurs, in most instances, in the end coils. It may consist of a slight rubbing between adjacent coils, when these close, or of rubbing between the coils and the spring seat. Tapered springs are an advantage in this connection since they lend themselves to damping of both types, particularly at the larger end. Barrel-shaped springs offer advantages if the spring seat is cup-shaped so that the outside of the end coils may be encouraged to rub on the side of the cup.

It may be mentioned in passing that vibration dampers have been designed and tried,* but experience has suggested that it is better practice to put the extra weight in the spring to allow for the increase in stress with surging.

It has been pointed out that the strain during reflection of a disturbance is double that due to the same disturbance when it affects any part of the spring away from the ends. This applies to perfect reflection. The length of wire affected by this maximum strain depends on the form of the wave. If the wave has a decided peak, then theoretically the maximum effect occurs only at the extremity of the spring. In actual practice this point is not well-defined, since it is the point where the working turns make first contact with the turn forming the flattened end. It is not a fixed point, but varies with the amount of extension or compression of the spring. It is interesting to note that the majority of fractures due to surging do not occur here, but occur between one-half and one full working turn from the end.

It is well known that the effect of surging can be limited by designing the spring so that there is only a small clearance between the coils at maximum lift of the cam. In such cases, when surging occurs, the compression wave passing along the spring causes closing of the coils which limits the maximum stress due to the surge. The pitch between the last working turn and the flattened end varies from zero at the first point of contact to the normal value at some point from one-half to one full turn along the spring. It seems apparent that the stress reached in closing the first half turn will be less than the maximum stress possible in the next half turn. This probably explains why fractures due to surging do not occur at the extreme end.

The variation of pitch towards the end of a spring is worth considering. With a uniform spring the pitch is constant up to the point where it is affected by the flattened end. Suppose that, starting, say, two full turns from the end, the pitch is gradually decreased, becoming zero at contact with the flattened turn. In such a case, by judicious selection of pitch variation, the point whose maximum possible stress is unsafe could be well removed from the zone of reflection, which is the zone of tendency to develop the double strain. In addition to limiting the maximum stress in the end coils such a variation in pitch would have other important effects: Amongst these are the following:—

1. The form of the wave would be altered during reflection. From consideration of energy it can be shown that the general tendency would be to flatten out the wave and remove the peaks or points of maximum intensity. It has been shown that one of the measures of surge intensity is the change in strain energy per unit length of wire. If, at the " stationary " point, during reflection, the strain energy per unit length of wire is limited by closing of the coils, this also limits the intensity of the reflected wave. Under these circumstances, the form of the reflected wave is a function of the spring design. This applies to the surge causing local compression, which, in valve springs, is more pronounced than the surge causing local extension.

* " The Surging of Engine Valve Springs." Engineering Research Special Report No. 10.

2. As the load on the spring is increased, the effective length of the spring decreases owing to closing of the end turns. This means that the load-deflection curve of the spring will not be a straight line. When surging occurs, the end turns close during reflection of the surge. The energy per unit length of wire in the closed turns is then a function of the spring design and not of the form of the surge wave. If the severity of the surge increases, the change in total energy causes closing of a greater length of the spring, so the position of the centroid of the wave during reflection varies with the intensity of the disturbance. In other words, the length of spring that determines the frequency changes with the severity of the surge. From this it follows that the period of vibration alters, and this may be arranged to hamper resonance.

In addition to variation in pitch, the closing of the end turns may take place at the larger end of a tapered spring. If the pitch in such a spring is uniform, then as the load on the spring is increased the turns at the larger end are the first to close. With barrel-shaped springs the conditions will be reversed.

The author wishes to express his thanks to Prof. F. C. Lea, O.B.E., D.Sc., of the University of Sheffield, for his kind advice and helpful criticism in the preparation of the paper.

Appendix

Notation used:

F = rate of spring: *i.e.*, the load which causes unit change in length.
w = mass per unit length of spring under any load.
l = effective length of spring under any load.
W = mass of effective part of spring $= wl$.
x = distance along axis of spring.
u = displacement of any point in the spring along the axis of the spring.
v_s = speed of propagation of the surge wave (along the spring).
v_w = speed of propagation of the surge wave (along the wire).
n = frequency of surge wave in vibrations per minute.
R = radius of curvature of wire (the mean coil radius).
ρ = density of material of spring.
N = modulus of rigidity of material of spring.
t = number of effective turns in the spring.
d = diameter of wire.

1. *Speed of Propagation of Disturbance*

Under disturbed conditions, the change in unital strain over a length δx is $(\partial^2 u/\partial x^2)\,\delta x$.

The resultant force on the specimen element is

$$F l\,(\partial^2 u/\partial x^2)\,\delta x = (w/g)\,(\partial^2 u/\partial t^2)\delta x$$
$$\therefore F l\,(\partial^2 u/\partial x^2) = (w/g)\,(\partial^2 u/\partial t^2).$$

The solution for the equation is

$$u = f(x + vt) + \phi(x - vt)$$

where

$$v = (Flg/w)^{\frac{1}{2}}.$$

The disturbance thus travels along the spring at a speed v_s given by

$$v_s = (Flg/w)^{\frac{1}{2}} \text{ or since } W = wl$$
$$v_s = l\,(Fg/W)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

With the usual formulæ for helical springs

$$F = Nd^4/64R^3t \quad \text{and} \quad W = 2\pi Rt\,(\pi/4)\,d^2\rho.$$

Substituting these,

$$v_s = (1/\pi)\,(l/t)\,(d/R^2)\,(Ng/32\rho)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (2)$$

For some purposes it is more convenient to express the speed of propagation as a speed along the axis of the wire instead of along the axis of the spring. Neglecting the angularity of the coils

$$v_w = 2\pi R v_s/\text{pitch} \quad \text{and} \quad \text{pitch} = l/t,$$

$$\therefore v_w = (d/R)\,(Ng/8\rho)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

It is to be noticed from equations (2) and (3) that v_w is independent of the stress in the springs, but v_s varies directly as the length and hence varies with the stress.

2. *The Frequency of the Spring*

The period of vibration of the spring is the time taken for a disturbance to travel twice the length of the spring, so the frequency in vibrations per minute is

$$n = (v_s/2l)\,60.$$

Substituting for v_s from equation (1)

$$n = 30\,(Fg/W)^{\frac{1}{2}}.$$

If F is in lbs. per inch and W is in lbs.,

$$n = 588\,(F/W)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The frequency of the spring is thus independent of the extension or compression of the spring unless the effective number of coils is altered by such extension or compression. It should be noticed that for the true value of the frequency W should be taken as the mass of the effective coils in the spring.

3. *The Effect of an Impulse applied to the End of a Spring*

It is proposed to consider here an impulse applying a given movement to the end of a spring. Under these circumstances the energy in the impulse is proportional to the resistance to the motion. It is assumed further that no closing of the coils takes place during the application of the impulse.

(*a*) *The Effect of a Single Impulse of Uniform Velocity*

Since initial strain is the ratio (change in length) / (length in unstressed condition), it is convenient to consider the spring in the first instance as starting from the unstressed condition.

Consider an unstressed spring initially at rest.

Let v_{so} = speed of propagation of a disturbance along the spring.

V = speed of the end of the spring during application of the impulse.

At the end of a time δt from the start of the motion, the wave front has travelled a distance $v_{so}\,\delta t$.

The end of the spring has moved $V\delta t$.

$\therefore$ the unital strain in the length $v_{so}\,\delta t = e = -V/v_{so}$.

(*b*) *The Effect of Initial Stress in the Spring*

Consider now a spring at rest but with an initial uniform strain given by

$$S = (v_{sl}/v_{so}) - 1 \quad . \quad . \quad . \quad \text{See equation (1)}$$

Where S is the unital strain in the spring, v_{sl} is the speed propagation of a disturbance in the stressed spring, and v_{so} is the speed of propagation of a disturbance in the unstressed spring.

If the end be moved at a constant speed V, then at the end of a time δt the total strain in the length $v_{sl}\delta t$ is $-V\delta t$.

The length $v_{sl}\delta t$ represents a length in the unstressed spring of

$$\{\, v_{sl}/(1+S)\,\}\ \delta t,$$

$\therefore$ the change in unital strain $= -V/v_{so}$; that is, the change in unital strain is

directly proportional to the change in speed of the wire movement and is independent of the initial compression in the spring.

Hence, in all cases, the change in unital strain accompanying a change in speed of wire movement with a disturbance travelling along a spring is given by

$$e = -V/v_{so} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where V = change in speed of movement of the wire.

v_{so} = speed of propagation of a disturbance in the unstressed spring.

4. *The Change in Stress caused by a Disturbance*

The change in unital strain caused by a change V in the speed of wire movement with a disturbance travelling along a spring is, from equation (5)

$$e = -V/v_{so}.$$

The local change in axial load is $-Fl_o e$ or $Fl_o V/v_{so}$, where l_o is the length of the unstressed spring.

The change in stress = change in load $\times R/(\pi d^3/16) = 16Fl_o VR/\pi d^3 v_{so}$.

With the usual formula for helical springs $F = Nd^4/64R^3 t$, and from equation (2) $v_{so} = (1/\pi)(l_o/t)(d/R^2)(Ng/32\rho)^{\frac{1}{2}}$. Substituting these, the change in stress due to a change V in the speed of wire movement is

$$V(2N\rho/g)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

One point to be noticed is that the change in stress resulting from a given movement of the end is independent of the dimensions of the spring, provided the end coils do not close during the application of the impulse.

5. *The Energy Imparted by a Given Movement of the End*

Let the end be moved at a constant speed V for a time ∂t. The resistance to the motion is $-Fl_o e$ and from (5), provided the coils do not close $e = -V/v_{so}$.

Hence the resistance to the motion is $Fl_o(V/v_{so})$.

The total energy imparted is given by the product (resistance to motion $\times$ distance moved).

In time ∂t the distance moved is $V\partial t$, so the energy imparted is

$$(V^2/v_{so})\, Fl_o \partial t.$$

The length affected is $v_{so}\partial t$, so the energy imparted per unit length of spring is

$$(V^2/v_{so}^2)\, Fl_o.$$

From equation (1)

$$v_{so}^2 = (Fl_o/w)\, g.$$

Substituting this, the energy imparted per unit length of spring is

$$wV^2/g \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

That is, the total energy imparted is 2 $\times$ kinetic energy. The volume per unit length is w/ρ, so the energy imparted per unit volume is

$$\rho(V^2/g) \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

6. *The Distribution of Energy in the Propagation of a Single Disturbance*

In the torsion of a cylindrical bar, with a given maximum stress q the strain energy per unit volume is given by

$$(\tfrac{1}{4})(q^2/N).$$

From equation (6) the change in stress due to a change V in the speed of wire movement is

$$q = V(2N\rho/g)^{\frac{1}{2}}.$$

Hence the strain energy per unit volume $= \tfrac{1}{4}V^2(2N\rho/Ng) = \tfrac{1}{2}\rho(V^2/g)$ (9)

The kinetic energy per unit volume $= \tfrac{1}{2}\rho(V^2/g)$.

Strain energy + kinetic energy $= \rho(V^2/g)$ = total energy from equation (8). Hence during unidirectional propagation of a disturbance

the strain energy per unit volume = the kinetic energy per unit volume (10)

7. *The Overlapping of Disturbances Travelling in Opposite Directions*

Consider the meeting of two disturbances travelling in opposite directions in a spring.

Let the speeds of wire movement be V_1 and V_2.

From equation (5) the unital strains are $-V_1/v_{s0}$ and $-V_2/v_{s0}$.

From equation (8) the disturbance energies per unit volume are $\rho (V_1^2/g)$ and $\rho (V_2^2/g)$.

The sum of the disturbance energies is

$$(\rho/g)(V_1^2 + V_2^2).$$

At the instant of overlap the speed of wire movement is the difference of the two speeds, that is $V_1 - V_2$.

The unital strain is the sum of the two disturbance strains, that is

$$(V_1 + V_2)/v_{s0}.$$

The energy per unit volume = kinetic energy + strain energy

$$= \tfrac{1}{2}(\rho/g)(V_1 - V_2)^2 + \tfrac{1}{2}(\rho/g)(V_1 + V_2)^2$$

$= (\rho/g)(V_1^2 + V_2^2)$, which is the same as before the disturbances met.

The waves that pass on in each direction must fulfil the condition (10) for unidirectional propagation. This is fulfilled if the waves proceed along the spring as before overlap.

Two main types of overlap may occur. These are:—

(1) The overlap of waves of like sign.

(2) The overlap of waves of unlike sign.

In the former type the strain during overlap is greater than that corresponding to the speed of wire movement. If the waves are of similar intensity the resultant strain is the sum of the individual strains and the speed of wire movement is zero. This gives a node.

In the latter type of overlap, the strain during overlap is less than that corresponding to the speed of wire movement.

8. *Reflection at a Fixed End*

Consider the reflection at a fixed end of a disturbance represented by a speed of wire movement V and a unital strain $-V/v_{s0}$. It is assumed that the coils do not close during reflection.

During reflection, the speed of wire movement is zero. This, as has been shown, is a condition for the overlap of two disturbances of like sign and the same intensity, so the reflection strain is the sum of the two strains, that is

$$-2V/v_{s0} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Hence during perfect reflection at the ends, the strain caused by a disturbance is twice that caused by the same disturbance moving along the spring.

9. *The Effect of Continued Periodic Motion of One End of a Spring*

The following assumptions, which need little justification, are required for a study of the effects of continued motion of one end of a spring:—

(1) Waves cross each other and pass on unaffected by the overlap.

(2) Provided the coils do not close, waves reflect from a fixed end and return along the spring unaltered.

(3) Provided the coils do not close, an additional disturbance added by a movement of end during reflection of a disturbance adds itself to the initial disturbance.

Surge effects are most serious when resonance occurs. This requires a periodic motion of the end of a spring such as that applied by a cam in an internal combustion engine. In the majority of cases it can be shown that a periodic motion is a sum of a number of simple harmonic motions. These consist of a fundamental and harmonics of varying degree. It is proposed to deal here with the case of simple harmonic motion so that general conclusions can be drawn regarding the majority of periodic motions.

10. *The Case of One End Moved with Simple Harmonic Motion*

Let the movement of the end be $C \sin wt$.

The wave front reaches a point distant x from the end after a time x/v_{so}, where x is measured in the unstressed spring. The movement of the wire at the point x is

$$C \sin w(t - x/v_{so}).$$

At t seconds after the start of the end movement, the displacement at the point x is

$$u = \int_{x/v_{so}}^{t} C \sin w(t - x/v_{so})\, dt = (C/w)\{1 - \cos w(t - x/v_{so})\}.$$

The unital strain is

$$e = \partial u/\partial x = -(C/v_{so}) \sin w(t - x/v_{so}).$$

The wave-front reaches the fixed end after a time l_o/v_{so}, where l_o is measured in the unstressed spring. Reflection occurs, and the wave front again reaches the point x after a time $(2l_o - x)/v_{so}$. The conditions at x are then obtained by taking the speed of wire movement as the difference of the individual speeds of the overlapping waves, and the unital strain as the sum of the individual strains. Thus at any instant after a time $(2l_o - x)/v_{so}$, the speed of wire movement at

$$x = -C \sin w\{t - (2l_o - x)/v_{so}\} + C \sin w(t - x/v_{so}),$$

and the unital strain at

$$x = -(C/v_{so}) \sin w\{t - (2l_o - x)/v_{so}\} - (C/v_{so}) \sin w(t - x/v_{so}).$$

In studying the conditions of resonance, it is convenient to refer to the conditions at x at the instants the wave front returns to the working end of the spring. This occurs at the times $2l_o/v_{so}$, $4l_o/v_{so}$, $6l_o/v_{so}$ . . . . nl_o/v_{so}, where n is an even number.

The conditions at time $2l_o/v_{so}$ can now be stated.

Calling the speed of wire movement V_2

$$V_2 = C \sin (w/v_{so})(2l_o - x) - C \sin (w/v_{so})\, x = 2C \sin (w/v_{so})\, l_o (1 - x/l_o) \cos (w/v_{so})\, l_o.$$

Calling the unital strain e_2

$$e_2 = -(C/v_{so}) \sin (w/v_{so})(2l_o - x) - (C/v_{so}) \sin (w/v_{so})\, x$$
$$= -(C/v_{so}) \cos (w/v_{so})\, l_o (1 - x/l_o) \sin (w/v_{so})\, l_o.$$

Continuing on the same lines, it can be shown that at time $4l_o/v_{so}$ the speed of wire movement is

$$V_4 = C \sin (w/v_{so})(4l_o - x) - C \sin (w/v_{so})(2l_o + x) + V_2$$
$$= 2C \sin (w/v_{so})\, l_o (1 - x/l_o) \cos (w/v_{so})\, 3l_o + V_2.$$

Also, at time $4l_o/v_{so}$ the unital strain e_4 is

$$e_4 = -(C/v_{so}) \sin (w/v_{so})(4l_o - x) - (C/v_{so}) \sin (w/v_{so})(2l_o + x) + e_2$$
$$= -(2C/v_{so}) \cos (w/v_{so})\, l_o (1 - x/l_o) \sin (w/v_{so})\, 3l_o + e_2.$$

For the general case, at time nl_o/v_{so} where n is an even number, the speed of wire movement is

$$V_n = C \sin (w/v_{so})(nl_o - x) - C \sin (w/v_{so})\{(n-2)\, l_o + x\} + V_{n-2}$$
$$= 2C \sin (w/v_{so})\, l_o (1 - x/l_o)[\cos (w/v_{so})\, l_o (n-1) + \cos (w/v_{so})\, l_o (n-3) + \ldots$$
$$+ \cos (w/v_{so})\, 3l_o + \cos (w/v_{so})\, l_o].$$

The bracket contains the sum of cosines of angles in A.P.

1st angle $= (w/v_{so})\, l_o$; common difference $= (2w/v_{so})\, l_o$; number of terms $= n/2$.

Hence the sum of the series

$$= \cos (w/v_{so})\, l_o \{1 + \tfrac{1}{2}(n/2 - 1) \times 2\} \sin (w/v_{so})(n/4)\, 2l_o / \sin (w/v_{so})\, l_o$$
$$= (\tfrac{1}{2}) \{\sin (w/v_{so})\, nl_o / \sin (w/v_{so})\, l_o\}.$$

From this, the speed of wire movement is

$$V_n = C \sin (w/v_{so})\, l_o (1 - x/l_o) \sin (w/v_{so})\, nl_o / \sin (w/v_{so})\, l_o \quad . \qquad (12)$$

Again, for the general case, at time nl_o/v_{so} the unital strain is

$$e_n = -(C/v_{so}) \sin (w/v_{so})(nl_o - x) - (C/v_{so}) \sin (w/v_{so})\{(n-2)\, l_o + x\}\, e_{n-2}$$
$$= -(2C/v_{so}) \cos (w/v_{so})\, l_o (1 - x/l_o)[\sin (w/v_{so})\, l_o (n-1) + \sin (w/v_{so})\, l_o (n-3) + \ldots$$
$$+ \sin (w/v_{so})\, 3l_o + \sin (w/v_{so})\, l_o].$$

The bracket contains the sum of sines of angles in A.P.

1st angle $=(w/v_{so})\,l_o$; common difference $=(2w/v_{so})\,l_o$; number of terms $=n/2$.

Hence the sum of the series

$$=[\sin(w/v_{so})\,l_o\,\{1+\tfrac{1}{2}(n/2-1)\times 2\}\sin(w/v_{so})(n/4)\,2l_o]/\sin(w/v_{so})\,l_o$$
$$=\{\sin^2(w/v_{so})(n/2)\,l_o\}/\{\sin(w/v_{so})\,l_o\}.$$

From this, the unital strain is

$$e_n=-(2C/v_{so})\cos(w/v_{so})\,l_o(1-x/l_o)\ \{\sin^2(w/v_{so})(nl_o/2)/\sin(w/v_{so})\,l_o\} \qquad (13)$$

Let the period of the S.H.M. be m times the period of the spring vibration, then since the period of the spring vibration is $2(l_o/v_{so})$

$$(2l_o/v_{so})\,m=2\pi/w$$
$$\therefore wl_o/v_{so}=\pi/m \qquad (14)$$

Substituting this in equations (12) and (13) gives

$$V_n=C\sin(\pi/m)(1-x/l_o)\{\sin n(\pi/m)/\sin\pi/m\} \qquad (15)$$

and

$$e_n=-(2C/v_{so})\cos(\pi/m)(1-x/l_o)\{\sin^2(n/2)(\pi/m)/\sin(\pi/m)\} \qquad (16)$$

If m is greater than 1, $\sin\pi/m$ cannot be zero for finite values of m, so the maximum amplitude is limited. The maximum possible value of V_n is

$$V_n=C\{\sin(\pi/m)(1-x/l_o)\}/\{\sin(\pi/m)\}.$$

It is obvious that when m is greater than 2, the speed of wire movement can never exceed C the maximum velocity of the S.H.M.

To get a just basis of comparison for unital strain, the amplitude of the S.H.M. should be independent of frequency. This condition is fulfilled by writing $A/m=C$ in equation (16). If m is greater than 1, the maximum possible value of unital strain is

$$e_n=-(2A/mv_{so})\{\cos(\pi/m)(1-x/l_o)\}/\{\sin\pi/m\}.$$

It can be shown from this that the maximum unital strain decreases as m increases.

Hence if m is greater than 1, that is, if the period of the S.H.M. is greater than the period of the spring vibration, the speed of wire movement and the unital strain are not excessive, no matter how long the end movement is continued.

The critical conditions arising from resonance are found when the period of the S.H.M. is an exact submultiple of the period of vibration of the spring, that is, when $m=\frac{1}{2}, \frac{1}{3}, \frac{1}{4}$, etc. When this occurs, it can be shown from equation (15) that V_n has the following values with continued motion of the end of the spring.

n	2	4	6	8
V_n	$2C\sin(\pi/m)(1-x/l_o)$	$4C\sin(\pi/m)(1-x/l_o)$	$8C\sin(\pi/m)(1-x/l_o)$	$16C\sin(\pi/m)(1-x/l_o)$.

The effect gradually increases, indicating that this is the condition for severe surge.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—I notice that Colonel Lahm, in his recent Wilbur Wright Lecture, refers to the Wright brothers as the "inventors of the airplane" (*sic*).

The achievements of the Wright brothers in the field of artificial flight have always been regarded with the utmost admiration in this country. Their fame, as the first to produce a power-driven, man-lifting aeroplane is undying, and the ingenuity, skill, courage and patience they displayed in their undertaking are object lessons to us all.

But they are not the inventors of the aeroplane. If it had been possible for the Wright aeroplane engine to have been produced in the year 1848, the English-

man, Stringfellow, could have produced the man-lifting aeroplane and human flight would have followed inevitably. Sir George Cayley was acquainted with the properties of the aeroplane even before Stringfellow.

The Wright brothers are, unquestionably, the pioneers " par excellence " of the man-lifting aeroplane and will be always held in honour for their achievements, but I am sure that they would be the first to disclaim the title of inventors of the aeroplane.

Yours faithfully,

W. O. MANNING, F.R.Ae.S.

31st May, 1933.

REVIEWS

Lubricating and Allied Oils

By Elliott A. Evans, F.C.S., M.I.P.T. Published price 9/6.

Mr. Elliott is chief chemist to Messrs. C. C. Wakefield and Co., Ltd., and this book, as might be expected, contains a large amount of information on oils. It starts with some interesting information on the history of the subject, contains chapters on Physical Tests, Chemical Tests, Decomposition of Petroleum, Oleography, Selection of Lubricants, etc.

As might be expected, much of the information is of more interest to the chemist rather than to the engineer, but the latter will be all the better for full information on such tests as viscosity tests and flash point as he will be better able to judge the value of such tests on the oils that he is using. Chemical tests are of less direct interest, but they are of importance when such matters as sludging may cause trouble, or in connection with deposits in the cylinders or on the pistons of internal combustion engines, etc. The only question that will arise is how far the working conditions can be considered as being represented in the laboratory tests.

The engineer will naturally turn with interest to the chapters on the employment of oil. These chapters are, perhaps unavoidably, less informative than might be hoped. The reason seems to be that lubrication is almost entirely an experimental science and that no satisfactory theory as to why one chemical liquid lubricates and why another does not has ever been developed. That it has something to do with the shape and size of the molecule seems certain, but the exact connection has yet to be traced. Viscosity is of unquestionable importance, but many viscous liquids are useless as lubricants.

Oils for aero engines are discussed in a short paragraph, and it is clear that the author prefers an oil containing castor for this purpose owing to the high loads on the bearings and the great reliability required. His remark that a plain mineral oil causes more dirt in an engine than castor oil is not consistent with earlier experience. Those who have had to run them will remember the caking caused by castor oil on engines of the Gnome type. Mineral oils have been extensively used in aero engines in America, with satisfactory results. They have the advantage of being cheaper than oils containing castor and are more easily obtainable in out of the way places. It is inconvenient to be tied to a particular brand of oil now that aeroplanes can fly to all parts of the world.

The book is one that should be read by all users of lubricants.

Simplified Aerial Navigation

J. A. McMullen. Chas. Griffin, London. 1933. 5/-.

This is an excellent little book which deals in a clear and comprehensive way with Aerial Navigation by Dead Reckoning. Compass deviations are explained in the opening chapters and the methods of adjusting these instruments and of

using protractors are fully described. The author deals with the parallelogram of forces, explains how courses are set out, and devotes a special chapter to navigation for the lone pilot.

This is a most useful work for those commencing the study of aerial navigation and can be thoroughly recommended to private owners, who will find in it sufficient information to enable them to find their way about. It would be improved by devoting a little more space to maps, such matters as contour lines or the mauve lines indicating international air routes, which latter are not found on the older maps, deserve consideration in connection with map reading.

The Notebook of Sir George Cayley

Published by the Newcomen Society and Edited by Mr. J. E. Hodgson. W. Heffer and Sons. 7/6 net.

This notebook is a remarkable relic of a remarkable man. Born in 1773, Sir George Cayley died in 1857, and during the whole of his working life he devoted the time which could be spared from the management of his ancestral estates to scientific experiments.

Although the subject which had the greatest attraction for him was that of flight, he seems, as was said of another famous man, "to have taken all knowledge for his province," and the breadth of his mind is well illustrated by the diversity of the notes he has made in this book.

There is a detailed account of the parturition of lambs, notes on lunar halos, rainbows, steam engines, brickmaking, mock suns, feed for horses, mortality from smallpox, motion of projectiles, and many other subjects, but the numerous notes on aeronautical matters, which take up, perhaps, two-thirds of the book, show the direction in which his mind preferred to work, and it is on these notes and on his other writings on this subject that his fame rests.

For he is unquestionably the Father of the Aeroplane, the first to discover the principles on which all present-day aeroplanes are constructed, the first to carry out scientific experiments on the lift of aeroplane wings, and the first to construct an aeroplane model which was stabilised with a tail possessing both horizontal and vertical surfaces. This machine, which he built in the year 1804 and used for gliding experiments, is the ancestor of all modern aeroplanes.

But his work did not stop here, realising that flight depended on a light motor, he constructed and operated a motor using gunpowder as fuel, and made many experiments with hot air engines. His appreciation of the necessity of a low structure weight for aircraft led him to make many experiments on the strength of timber, and also led him to the invention of the suspension wheel; a fundamental advance in wheel construction without which modern road locomotion would be seriously hampered.

With the means at his disposal, limited as they were, he contrived to lay the foundations of the science of aeronautics, and the foundations he laid are still in use to-day. The age in which he lived was conspicuous for men of fame, pioneers of industry and mechanics, and with them he takes a worthy place as one of the outstanding figures of his time.

It is to Mr. Hodgson, the Hon. Librarian of this Society, that we are indebted for the discovery of and the editing of this notebook, and the aeronautical community owes him a deep debt of gratitude for the skill and care with which he has carried it out. It is well illustrated with Cayley's original sketches and has numerous notes which illuminate the text. A complete list of the Cayley papers is given in the appendix, many of which appear to be of great interest, and it is hoped that it may be possible to publish a selection from them at some time in the future.

Thanks are due to the Newcomen Society for the publication of this work. The style and quality of the printing leave nothing to be desired and the book is a most valuable contribution to the history of aeronautics.

The 560th Lecture read before the Royal Aeronautical Society since its foundation January 12th, 1866.

PROCEEDINGS

Fourth Meeting, Second Half, 68th Session

The Fourth Meeting of the second half of the 68th Session of the Royal Aeronautical Society was held in the rooms of the Royal Society of Arts, at 18, John Street, Adelphi, London, W.C.2, on Thursday, February 16th, 1933, when a paper on "Cloud Formation and its Effect upon Gliding" was presented by Sir Gilbert T. Walker, C.S.I., F.R.A.S., F.R.S.

In the chair: Mr. E. C. Gordon England, F.R.Ae.S., Member of Council.

The Chairman: He was particularly glad to have the opportunity of presiding on this occasion, because Sir Gilbert had been such a staunch supporter of the gliding movement in this country. He was a very active member of the Council of the British Gliding Association, and his advice and his very constructive opinions were valued at all times.

CLOUD FORMATION AND ITS EFFECT UPON GLIDING

BY

SIR GILBERT T. WALKER, C.S.I., F.R.A.S., F.R.S.

The importance of healthy relations between the sporting and the scientific sides of gliding is very great; and the fact increases the responsibility of my task this evening as well as the honour that the Council of the Aeronautical Society have done me in asking me to undertake it. The history of gliding on the continent shows that at times when financial or other difficulties have given cause for anxiety, some development suggested on the scientific side has re-kindled enthusiasm and given the movement a new vitality. Change is as essentially connected with a healthy sport as with a living organism. Nobody can visit the Wasserkuppe without being impressed by the zeal which prevails there; it is almost religious in its fervour, and although some of the neophytes of the hierarchy may be mere gymnasts fired with the team spirit, its bishops and its missionaries are inspired by their determination to advance knowledge. The developments occur on the side of meteorology as well as of aerodynamical design; for the co-operation of both is essential in order that the structure of the gliding machine may be adapted to the stresses to which it will be subject in its path through the somewhat turbulent regions to which the meteorologist would direct it. In order to emphasise these ideas I would like to make a short paraphrase from the account of the development of sail-flight during the years 1920-1930 given by Georgii, whose authority is unquestioned. He speaks of the crisis of 1924-5 and of the transformation of stagnation into the onrush of progress that has occurred since 1926; he attributes it partly to the creation of gliding schools and to the widespread provision of drawings of machines of standard types; but above all it is due to the systematic observations of vertical movements which have brought clouds and cold fronts into use and have given soaring methods a new foundation. Cloud sailing became established in 1928. It had long been known that there were possibilities under clouds, especially under cumulus clouds; but definite observations were scanty and in 1928 a scheme of measurement was organised; it included the rate of rise or

fall of power planes when gliding with the propeller stationary, and it was found that under clouds the machines could maintain their heights for times extending up to ten minutes. The speed of the up-currents was surprising; velocities up to 11 feet a second were measured, and as a sailplane of standard pattern travelling horizontally only falls 1.5 feet a second, it was manifest that cloud soaring had great possibilities. Sailing by means of cold fronts or line squalls and thunderstorms had also been established; by their means distances over 100 miles and heights of over 8,000 feet above the start had been accomplished; and heights of 13,000 to 15,000 feet appeared possible, with a corresponding increase in the horizontal length traversed.

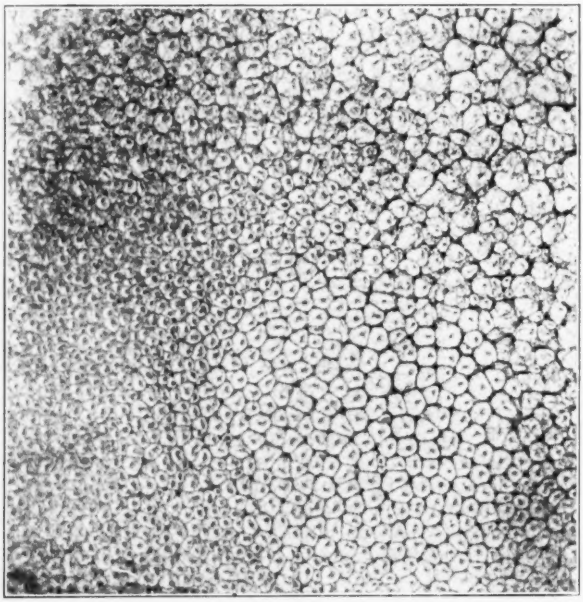


FIG. 1.

Before discussing the motions associated with the different types of clouds that can be observed in the sky it will be well to glance for a short time at the investigations that have been made in the laboratory. It was as far back as 1855 that E. H. Weber noticed a curious polygonal pattern in a thin layer of a solution of gamboge in spirit; under these conditions the spirit evaporates and the liquid is chilled at the upper surface, so that the top layers become heavier than those at the bottom; the equilibrium becomes unstable and some form of motion is inevitable. Subsequent experimenters, especially Bénard, have shown that when this motion has become steady it occurs in cells, usually pentagons and hexagons, with liquid rising in the centre of each and descending at the interfaces between the cells (Fig. 1). A very useful account of this work was given by Brunt in the *Meteorological Magazine* of February, 1925. The next advance was in 1920 when Idrac examined unstable liquids in motion along a trough. The liquid flowed more slowly near the bottom of the trough than it did at the free surface, so that there was a shearing motion between the top and bottom. When the liquid was unstable there appeared long straight vortices, alternately spinning in right-handed and left-handed directions with their axes

parallel to the direction of motion of the liquid, and therefore parallel to the direction of the shear (Figs. 2, 3). It had been supposed by these investigators that their results would have applications to cloud form. But there was no definite evidence on this point and it was impossible to overlook the analogy of

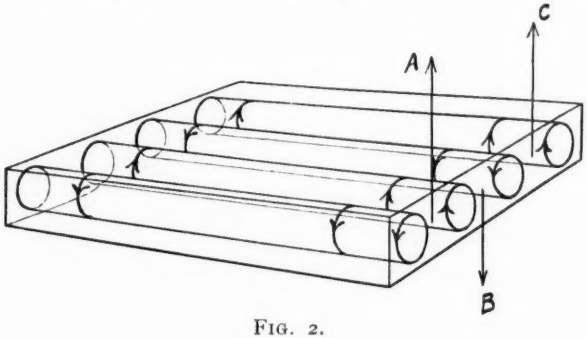


FIG. 2.

ordinary sea waves in which the direction of the waves is, of course, at right angles to the velocity of the wind relative to the water. Accordingly long roll clouds (Fig. 4) were supposed to form in the horizontal plane separating two air masses when the velocities of the wind in the two air masses were different; and the direction of the waves was supposed to be at right angles to the relative motion in the two masses, or transverse, as we may call it.

During the past six years experimental efforts have been made at the Imperial College and elsewhere to approximate more closely to the conditions

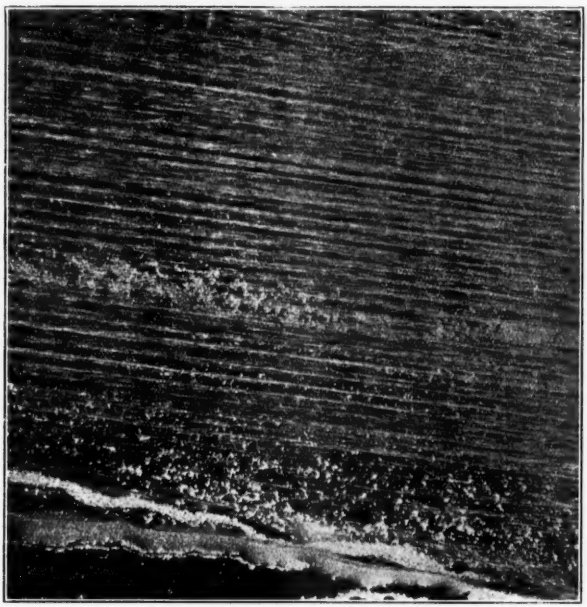


FIG. 3.

prevailing in the sky; there are, however, many features still unexplained. Much of the work has been done in a small wind channel about six inches wide and a third or a quarter of an inch deep; the steel bottom was warmed by electrical heaters and the glass top was left cool so that the air within became unstable; it was given the appropriate motion, the patterns produced being shown by smoke mixed with the air.

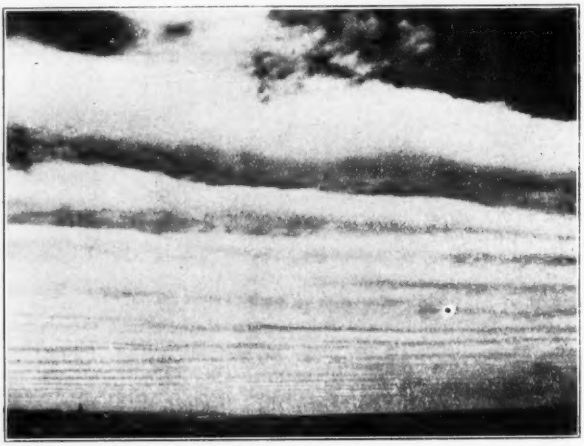


FIG. 4.

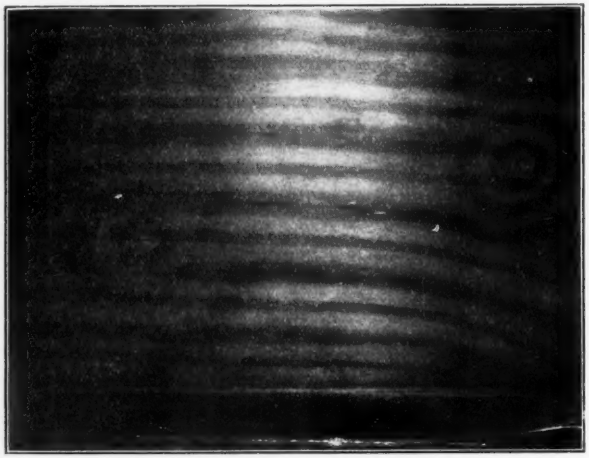


FIG. 5.

Beginning with Idrac's longitudinal vortices it was found that with a relative motion between the top and bottom of over an inch a second the space was filled with pairs of straight eddies alternately right and left-handed with their axes parallel to the shear between the top and bottom (Fig. 5). Thus there was in each a rotation combined with the forward movement, so that any particle

of air described a spiral; and under suitable conditions the spiral streamlines were easily visible (Fig. 6), those above and below a vortex moving in different directions when seen from above and so forming a kind of crossed pattern.

We have seen one picture of ordinary longitudinal rolls and they are found among low, medium and high clouds. Curiously enough their direction, at any rate in the lower and medium levels, is usually almost parallel to the direction in which they are travelling; we believe that it must be parallel to the relative motion of the top layer relative to the bottom, and we conclude that the increase

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FIG. 6.

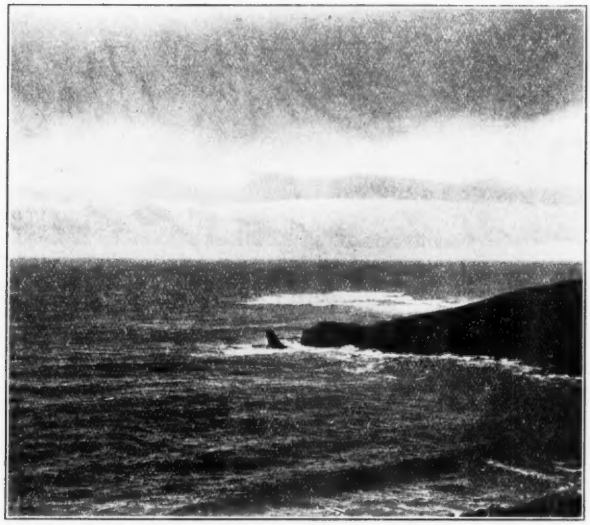

FIG. 7.

of wind with height produces bigger changes than does the change of direction with height. In Fig. 7, which I owe to Mr. A. C. Phillips, we have a typical longitudinal roll and can see that it is roughly parallel to the wind motion that produces the lower clouds. A typical photograph of high-level cloud vortices (Fig. 8) gives the impression that they are cylindrical shells, not solid cylinders; and it frequently happens at all heights that the shell is not complete, the cloud

dissolving on the side where the air is descending, so that we have a long scroll consisting only of the upper half of the cylinder. This seems to be visible almost daily in the trade wind region in the morning and evening when the low sun lights up the hanging edge of the scroll, but it is frequently to be seen in England. I owe an example of this (Fig. 9) to Mr. Cave, to whose unlimited

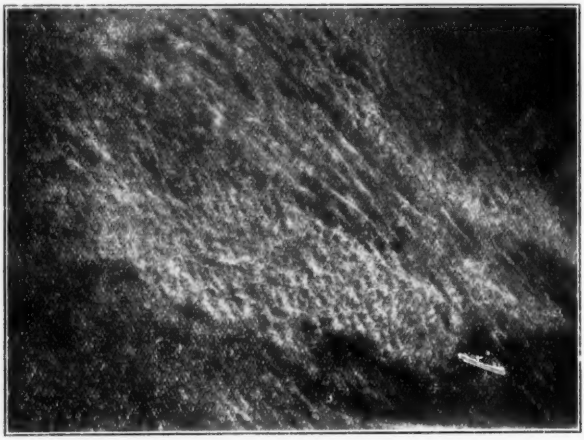

FIG. 8.

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FIG. 9.

generosity I am indebted for a number of photographs. When a longitudinal cloud roll is newly formed it is not easy to make out its structure, but when it is dissolving its spiral texture is almost a normal feature; that meteorologists have so long overlooked it affords an illustration of the melancholy fact that however plain a pikestaff may be it is very hard to see it until some person or some theoretical consideration tells us that it is there. I owe a conspicuous example

of spirals at a moderate height to Mr. A. C. Phillips (Fig. 10); but high clouds also produce spirals (see the top right hand side of Fig. 11) and at lower levels the dissolving of longitudinal rolls generally brings them out though they are not always conspicuous (Figs. 12, 13).

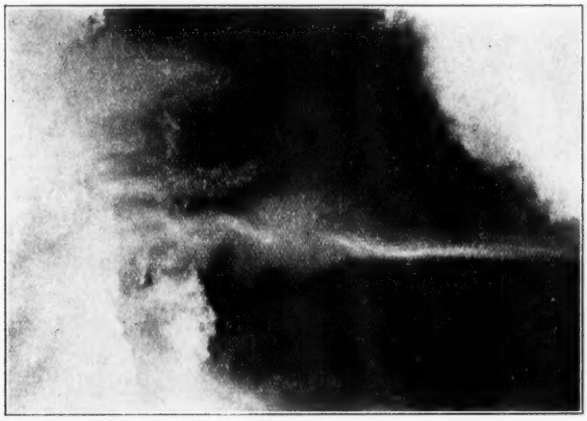

FIG. 10.

FIG. 11.

There is another type of cloud pattern in which there are rectangular cloudlets, usually separated by long lines at right angles. The usual explanation given was that relative motion between two layers first produced one set of lines as it produces sea waves; and that the first relative motion then died out and was replaced by one at right angles, setting up rolls perpendicular to

FIG. 12.

FIG. 13.

FIG. 14.

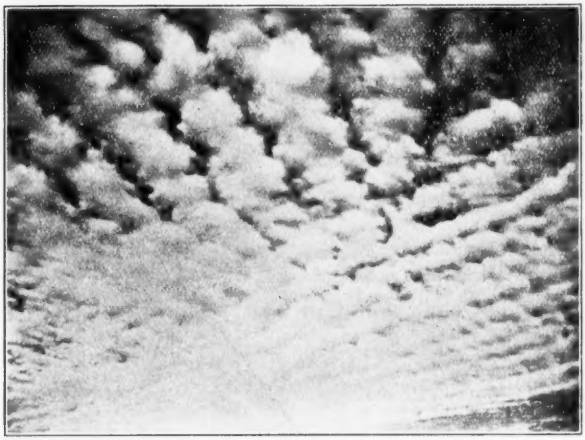

FIG. 15.

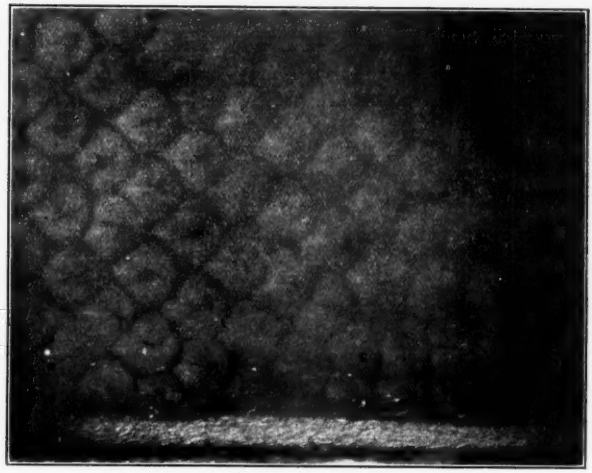

FIG. 16.

the first system. But this explanation breaks down hopelessly in view of the fact that the pattern develops from the outset with lines of cloudlets in both directions. Fig. 14 shows a rectangular cloud which has just formed, and Fig. 15 one in a more advanced state. These can be imitated in a tunnel by giving the air a somewhat slower movement than that corresponding to longitudinal vortices (see Fig. 16).

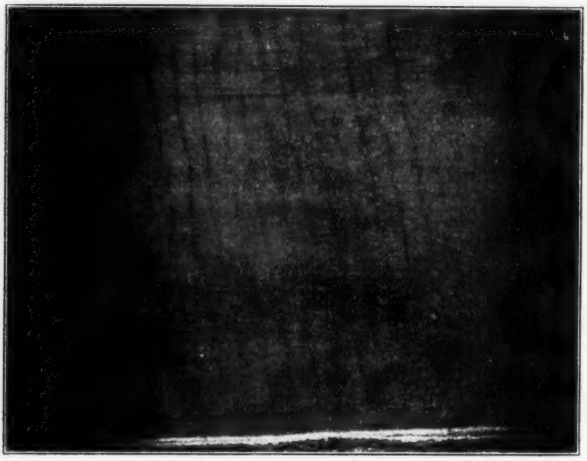

FIG. 17.

FIG. 18.

On reducing the air velocity still further a system of vortices at right angles to the air motion, or transverse vortices, appears, with rotation alternately in opposite directions (Fig. 17); but in these there is no motion along the vortices,

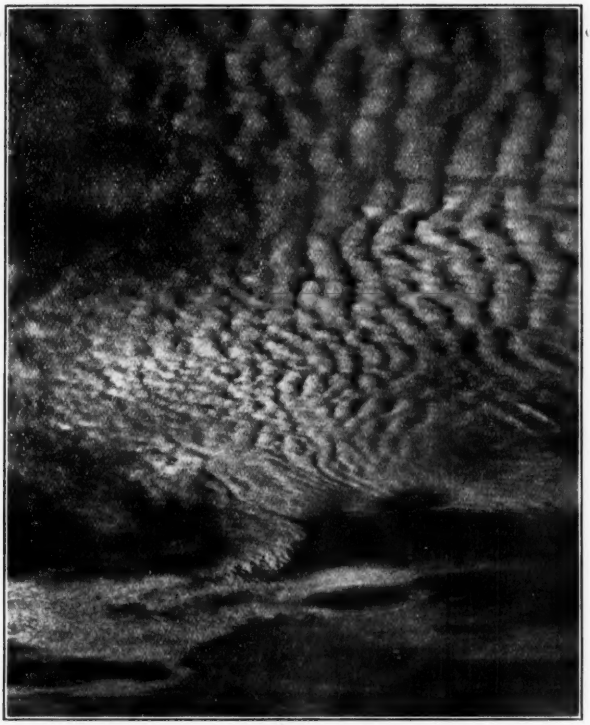

FIG. 19.

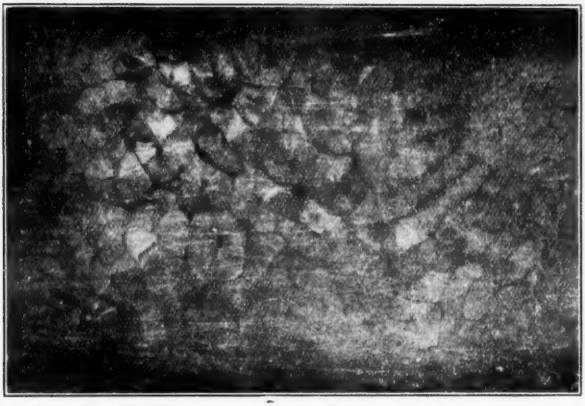

FIG. 20.

so that we have no spiral effects, and in the sky we often see a ribbed formation at right angles to the cloud rolls (Fig. 18). Both in the laboratory and in the sky such cloud lines, being associated with smaller velocities, are more distorted by chance disturbances; thus transverse rolls can usually be distinguished at

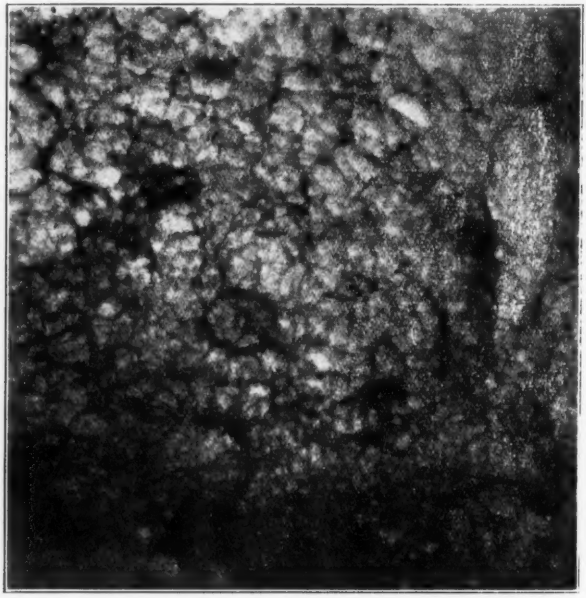

FIG. 21.

FIG. 22.

once from longitudinal ones by their branching and sinuous lines (Fig. 19) like those of sand ripples.

In order to get polygonal cells smoke was drawn in until the channel was

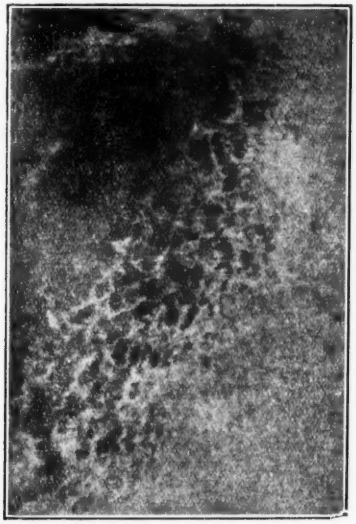

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FIG. 23.

FIG. 24.

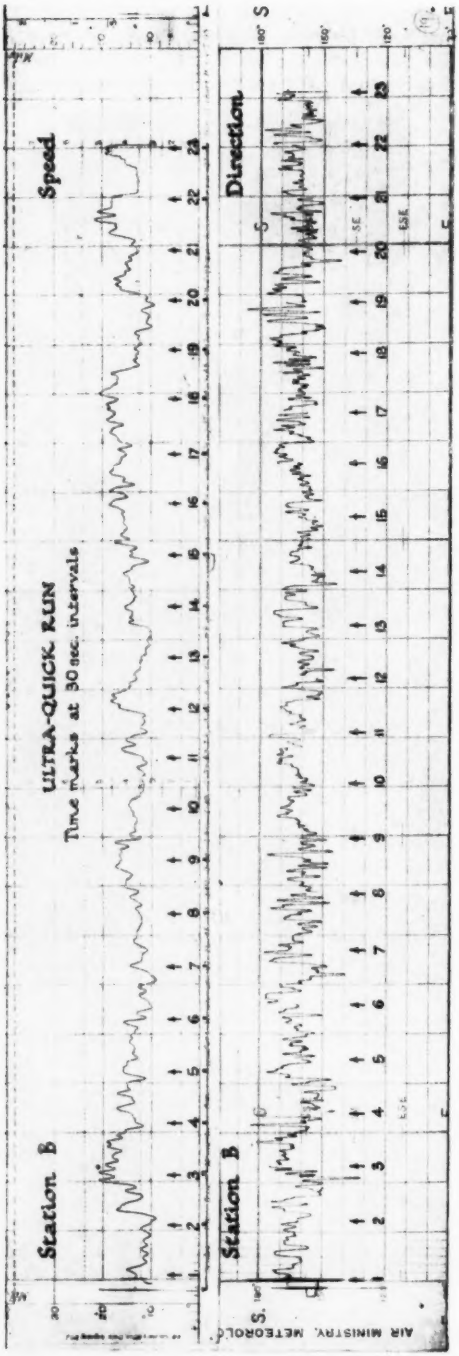

Station B
Speed
ULTRA-QUICK RUN
Time marks at 30 sec. intervals
Station B
Direction
S.
AIR MINISTRY. METEOROL.

FIG. 25.

full of vortices, all rotating alternately in opposite directions; as the forward motion diminished to zero, kinks would appear here and there convulsively, and this process would go on until there were no long portions without a kink and the channel was full of polygons (Fig. 20). Thus instead of looking on a cell as a region where air is rising in the centre and descending at the margin we may look on it as a single vortex like a smoke ring except that it has four, five or six kinks which make it polygonal. Regarding its relations with any one of the cells next to it the fact that contiguous vortices always rotate in opposite directions means that in the adjoining cell also air will descend at the margin and ascend in the centre. The similarity of the sky patterns (Fig. 21) to those of the laboratory indicates that these remarks are equally valid there. It is at first sight strange that in laboratory experiments, as usually carried out, the fluid rises in the middle of a liquid cell and descends in an air cell; but in the sky the air normally rises and by condensation causes cloudlets in the centre of a cell, while descent causes dissipation of the cloud and the appearance of blue sky in the interstices. This is confirmed by photographs from aeroplanes such

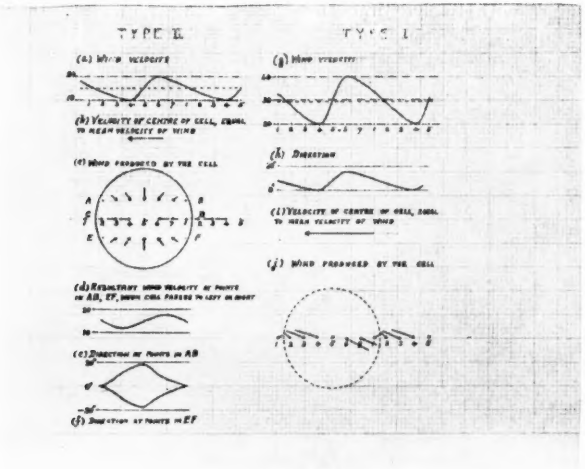


FIG. 26.

as the one before you due to Captain Douglas (Fig. 22); in them the dome shape of the cloudlets clearly implies an up-current in its centre. This shape provides the explanation of the characteristic of such cloudlets that their upper edges, from whatever direction we see them, are sharper than their lower edges. At times, however, we see cloudlets in which the motion is reversed, with air rising and cloud forming at the interfaces between cells, while blue sky shows through the descending air of the centre. Clouds of this type may be called "reversed" and the pattern "reticular" (Fig. 23); further, when the sun is low we may see the lower parts of these polygonal curtains strongly lit up while the upper parts are in shadow (Fig. 24).

A question of fundamental importance now arises—that of the vertical dimensions of a cell in nature. In laboratory work the smoke indicates the movement throughout the height of a cell; but in the air it often happens that owing to the high temperature of the ground the region in which conditions are unstable extends from the ground to a considerable height, and, although the cells presumably extend equally far upwards, the cloud would only appear at heights

dependent on the distribution of humidity, and might not appear at all. On the other hand, there appear to be occasions on which the regions of instability, and therefore the cells, do not reach to the ground. Bearing on this are the indications, both theoretical and experimental, that the horizontal diameter of a cell is two or three times its height; so that as the distance between the centres of two cloudlets is probably not more than 1,000 feet, the depth of a cell would then not exceed 500 feet, and the clouds are too high for it to extend to the ground. But the conditions on which both theory and experiment rest probably differ widely from the actual; if they were valid a cloud cell which reached to the ground would have a top whose diameter subtended over 90° at an observer over whom it was passing; and such an angular diameter is practically unknown, though, as we shall see later, cells of this type do extend at times to the ground. Hence we must regard the evidence as to the height of a cell so far adduced as insufficient. By far the best information known to me is that recently provided by the Meteorological Office in their *Geophysical Memoir*, No. 54, dealing with the superbly organised wind measurements made at Cardington; in addition to instruments with the ordinary time-scale of one inch to $1\frac{2}{3}$ hours, they employed a " quick run " with twelve times as open a scale and an " ultra quick run " 144 times as open. The authors divide their disturbances into two main types.

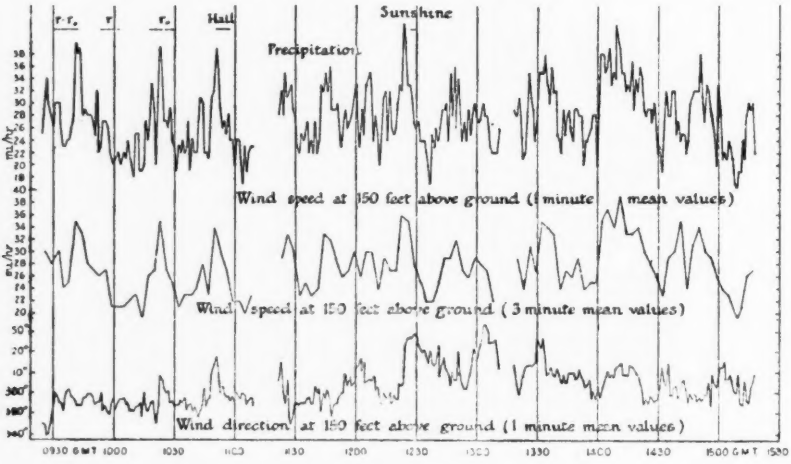


FIG. 27.

Of these (*a*) the larger, known as the " gust and lull," are most developed where the vertical temperature gradient is adiabatic or superadiabatic, and are therefore due to convection currents set up in an unstable atmosphere; on the other hand, their disturbances (*b*), which have a much shorter period, are little affected by the lapse rate and are eddies set up in the main air stream by obstructions such as trees and buildings, and of these the diameters are of the order of 50 or 100 feet. Regarding the larger type, they remark on page 8:—" If it were possible to arrange a perfectly still unstable atmosphere a regular motion would soon develop within it. The whole atmosphere would arrange itself into vertical compartments like a vast honeycomb, in each cell of which the air would rise in the centre and descend around the sides. The same effect would happen in a modified form if the air were in motion as a whole."

Now this statement, with which I agree, appears to me at variance with the theory developed on p. 60, in which the air is supposed to ascend at the rear-

ward margin of the cells. I propose, therefore, to let the records tell their own tale and to put before you the conclusions to which, in my view, they lead directly. For our examples of gusts and lulls we take those selected by the authors; these are to be found in their Plate I in the intervals from 3 to 7 and from 12 to 13½ (Fig. 25). It is clear, however, that there is no precise pattern which occurs regularly; all that we can say is that from time to time there is an air motion which seems to approximate roughly to a type.

The obvious feature in the graph giving the speed is the more rapid rise than descent; but in that giving the direction there seems to be no dependence on velocity. I propose, therefore, to take a typical curve, such as (*a*) in the diagram (Fig. 26) and see what is the meaning of it; the minor irregularities in speed and the entire deviations of direction are treated as accidental irregularities and ignored for the present. Let us think of the velocities at the successive points 1, 2, 3, . . . in (*a*) as due to the passage in (*c*) of successive points 1, 2, 3, . . . along the axis of a cell in its motion to the left; then the velocities at these points can be looked upon as made up of a velocity in the cel superposed on the mean velocity (*b*), and the cell velocities will be indicated by

FIG. 28.

the horizontal arrows; the region of maximum ascent will be at 5 and of maximum descent at 1½. So we take our cell walls at C, D, and draw the cell (*c*) for simplicity's sake as circular with winds blowing radially inwards. Of course it must be polygonal, including rectangular in this term, in order to fit in with surrounding cells; but the necessary modifications are easily made approximately and will not be large. We will next inquire what will happen if such a cell, instead of passing centrally over us, were to pass somewhat to the left as it would if the centre of the cell in our diagram moved along DC and its effect was observed at A. In that case the velocities would be those plotted along AB combined with the mean forward velocity, and it is easy to work out the corresponding graphs of velocity and direction which would be produced in an anemometer; they are given at (*d*), (*e*). The corresponding graphs for a passage to the right of the place of observation are (*d*) and (*f*). It may be noted that the direction graph in Plate I of the gusts beginning at 3 runs upwards with the gust while that at 12 runs downwards; it may perhaps be, therefore, that one cell passed to the left and the other to the right. Also the average time of passage of the cells of this type in Plate I is, in my opinion, something like

45 seconds, corresponding to a length of very roughly 300 yards; the estimate given in the Memoir is however materially greater, 3,000 to 8,000 feet.

We may glance for a moment at the gusts on a bigger scale, distinguished as Type I by the authors, occurring when thunderstorm clouds are present. Then, as seen in their Fig. 32 on p. 37 (Fig. 27), graphs of speed and direction tend to run parallel, *i.e.*, gusts are associated with veering; so we have drawn the direction graph (*h*) with this characteristic, and, assuming that the winds are due to the passage of a cell, have plotted at the successive points in (*i*) the winds that have to be combined with the mean wind (*j*) to give the winds of (*g*) and (*h*). The points of descent are, as before, at $1\frac{1}{2}$ and we now note that in addition to inflow from the ascending column at $4\frac{3}{4}$ there is a slight counter-clockwise rotation. The time of passage of such a cell, as shown by the Fig. 32 of the Memoir, is something between 10 minutes and 30 minutes; this is very much larger than the cell of the smaller gust, and, as its diameter is something between 4 miles and 13 miles, it is not surprising that rotation appears, just as it does with the more violent but smaller dust devil of the tropics.

FIG. 29.

The next question that arises is the strength of the up-current associated with the less violent gusts first discussed, such as are ordinarily associated with strato-cumulus clouds. A very rough indication is all that can be hoped for; and if we return to our diagram (Fig. 26) and suppose that the winds of 5 feet a second at 3 and 7 extend upwards to a height of 200 feet, it follows that the average up-wind over the circle of about 500 feet in diameter at a height of 200 feet is something like 11 feet a second. It should be remembered that the gusts selected as typical are apparently chosen for their size, and hence that 3 or 4 feet a second is more like the order of magnitude that we should expect; but, on the other hand, the inflow probably extends to considerably above 200 feet and the rate of ascent would be proportionally increased. We may expect then that under a cloud, where the cell that produces it extends down to the ground, a useful up-current exists over a fairly large area. Further, if the cloud occurs in rolls the useful area will be found in long lines parallel to them; such an area might, therefore, be of special advantage to a pilot whose route lay in the direction of the rolls.

Let us now see how far our conclusions are supported by the reports from pilots of actual experiences of vertical currents under clouds other than cumulus

and cumulo-nimbus, reports which are unfortunately very few in number. It has long been recognised that the clouds of the form called " castellatus," which are capped by tower-like protuberances, are produced by strong up-currents and are usually followed by thunderstorms (Fig. 28) ; accordingly it is not surprising that Lange experienced in a power machine, with the engine cut off, an up-current due to them of at least 25 feet a second. We are, however, more interested in the winds under the much more frequently occurring strato-cumulus clouds. Of these Höhndorf makes the important remark that under them the up-winds are of the same order of magnitude as under cumulus clouds. He says, further, that the chief turbulence associated with them lies below the cloud, that at the cloud level being materially less; and this suggests that the cell extends to an appreciable distance below the cloud.

Many observations have in recent years been made with small balloons which are loaded so far that their lift is just destroyed and are set free at various heights so as to indicate air currents. The object in view has been to study the

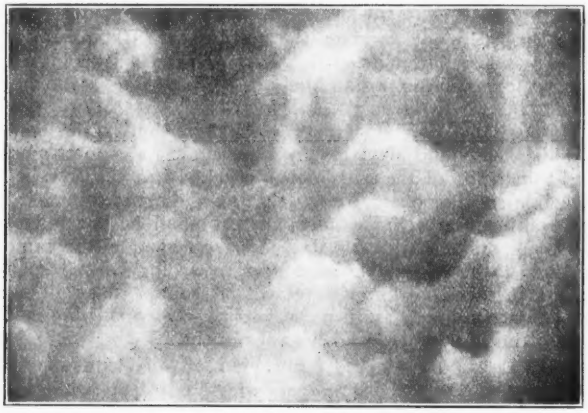


FIG. 30.

eddies produced by hills or the magnitudes of ordinary convection currents; but I have not seen any records of the effect produced by clouds of types other than cumulus.

The practical application of this analysis to soaring flight may now occupy our attention. I do not propose to say anything about the use of cumulus clouds or storm clouds because the subject has been, both fully and ably, treated by Kronfeld in several chapters of his book " On Gliding and Soaring." He there shows, for instance, that it is better for a pilot to try to find the up-current under a cumulus cloud before it reaches the ridge whose up-winds he is using rather than wait till the cloud is overhead; otherwise, in case of failure, return to the ridge may be impossible.

If cloudlets are passing overhead a pilot would attempt to use them for climbing as if they were cumulus clouds, as in Fig. 29, showing low cloudlets arranged in two systems of long perpendicular lines. He may wish to form an impression as to the height at which the up-current may be expected, and therefore to know whether it affects the surface winds. The Cardington records suggest a criterion; for with a mean wind of 15 to 20 miles an hour the passage of a cell produces variations of 3 to 5 miles an hour above and below the mean wind; but if the effect of the cells does not extend to the ground the oscillations are merely those of frictional eddies and probably do not exceed $1\frac{1}{2}$ miles an hour above and below

the mean. Thus an anemometer with a good exposure showing the actual velocity would have to be watched. It might be that gust and lulls occurred without clouds; and in that case, the up-current in the centre of the cell occurs, as our diagram showed, just after the lull and before the gust; thus the pilot should be able to locate the up-current and be prepared to describe a spiral inside it, remembering that it travels with the mean velocity of the wind. It may be noted that Kronfeld says of storm soaring that the pilot should take-off just before the violent wind; and this, as in our case, is the place of strongest convergence, so that the ascending current is most powerful. There is one other piece of advice that I would venture to give, namely, of regions to avoid. Reticular or reversed clouds are not often met with low down, though at greater heights they are fairly common; under them the cells have descending air columns in their centres and the up-currents around these are probably feeble. Mammato-cumulus clouds (Fig. 30) with their characteristic rounded lower surfaces which occur in thundery weather are presumably associated with descending currents and will be of little use to a pilot away from the influence of the hills. Any up-currents and down-currents other than those to be found in cells or in connection with storms and fronts are probably not strong; the former would tend to facilitate the formation of cloud and the latter its dissipation. Thus a weakening cloud showing a ragged or spiral formation is not so likely to be helpful as a growing one which is well rounded.

Finally, I would like to make it perfectly clear that the evidence on behalf of all that I have said upon the velocity of the air in connection with cells is incomplete and that some of the conclusions reached can scarcely be regarded as more than plausible suggestions. I hope that at gliding meetings it may become an established routine that reliable anemometers shall be carefully watched; or if recording instruments are available that their records shall be examined. Only then shall we learn to make reliable inferences regarding cells from the gustiness of the wind; and in this way knowledge will be gained that will be of value to meteorological science as well as to motorless flight, knowledge which will knit still more closely the inevitable bond between them.

Discussion

The Chairman: The closing sentences of the paper would be most encouraging to those in the gliding movement. They provided more than sufficient justification of the efforts of those who were attempting to soar successfully in the interests of science, and he expressed the hope that they would not disappoint Sir Gilbert in that respect. He could, of course, suggest some of the reasons why they had not done all that they ought to have done, but perhaps the matter was one for discussion in another place.

Mr. C. S. Durst: The picture which Sir Gilbert had given of the structure of the cells near the ground differed in some respects from that which he (Mr. Durst) had drawn originally in the Geophysical Memoir referred to in the lecture. He would not have troubled the meeting with those differences had there not been a possibility of a practical application in the view which he had taken.

(Mr. Durst exhibited a slide—Fig. 81 of Geophysical Memoir 54—showing the plan and section of the cells which he believed occurred.)

Referring to the plan, he indicated that there were horseshoe-shaped discontinuities, and the air was sinking at the peripheries of the horseshoes.

The practical point, he said, was that in the picture drawn by Sir Gilbert Walker the cells were circular. There was down-flow equally all the way round and up-flow in the middle. But in the picture as he (Mr. Durst) drew it the down-flow occurred principally at the rear of the horseshoes. The places at which greatest up-flow and greatest down-flow occurred were comparatively near together. No doubt there would be between them a layer which had neither

up nor down-flow, but the fact that those two flows were close together might mean that a glider proceeding down-wind would easily get into the area of maximum down-flow. If, however, the glider passed across wind from one cell into the next cell, it might avoid the area of greatest down-flow.

One piece of evidence, which was not mentioned in the paper, but which he considered supported his view, he put forward in a slide (Fig. 47 of G.M. 54) showing the analysis of a 10-minute record, there being arrows drawn to represent the wind for intervals of five seconds. The ends of these arrows, he pointed out, did not fall in a circle, but in an oval. If one cut out the short-period fluctuations and left only the long-period fluctuations, *i.e.*, those due to the cells he was discussing, one found that they would lie even more definitely in an oval. If Sir Gilbert Walker's theory were the right one, they should not lie in an oval, but in a circle, and Mr. Durst reiterated his belief that the cells were not uniform but were of horseshoe shape.

Commenting on the diagram exhibited by Sir Gilbert, illustrating the large-scale fluctuations, which Sir Gilbert had said were also circular, Mr. Durst exhibited a copy of it, together with simultaneous records of temperatures. If one examined these records closely one would find that the temperature fell when the gust was strongest. That meant, he believed, that the gust was composed of cold air, and that that cold air must be brought down from above, so that it was to be inferred that the gusts were descending.

Finally, he said that the pictures drawn by both Sir Gilbert Walker and himself were largely speculative. At the University of Michigan some important work was being done with even more anemometers than had been used at Cardington. He believed the results of that work would prove either Sir Gilbert's or his own view.

Mr. LOWE-WYLDE: He had listened to Sir Gilbert's theories with a certain degree of amazement. It was a great pity that there were no means of co-ordinating the information obtained by Sir Gilbert with that obtained by the gliding movement in this country. Such co-ordination had been rendered possible in Germany by reason of the fact that the necessary funds were voted, and the sooner the powers-that-be in this country, by the provision of funds and facilities, enabled us to do so, the sooner should we achieve real progress.

Captain G. F. MEAGER: On the occasion of the Gordon-Bennett race in America in 1927 the balloon in which he was travelling would frequently rise through the top of the clouds, then drop down into the clouds and rise again through the top, although no ballast was dropped. This alternate rising and falling had continued for hours, and he had attributed it either to up-currents or to superheat, but was still unable to decide which was the real cause. Perhaps Sir Gilbert could explain it.

Captain ENTWISTLE: Probably many who were associated with the gliding movement would be somewhat surprised to learn that there were definite up-currents associated with clouds other than the well-known types of cumulus and thunderstorm clouds, although, as we knew, soaring flights had taken place beneath such clouds even in this country. In the spring of 1930, starting from Itford Hill, Kronfeld had carried out a long soaring flight beneath a cloud which had looked very unpromising, judged by our ordinary conceptions. At the same time, Captain Entwistle regretted that Sir Gilbert had not found space in the paper for some discussion of the better known cumulus and thunderstorm clouds, because there was no doubt that, although we had a large amount of information on the vertical currents associated with them, a great deal had yet to be learned. He had rather hoped that the lecturer might have brought forward some new information regarding the magnitude and extent of the vertical currents associated with these clouds.

A matter in regard to which he was in some doubt was that of the extent of the upward currents underneath clouds of the strato-cumulus type, and he had

been surprised to hear it stated that the vertical currents under such clouds were of the same order of magnitude as those under a cumulus cloud, because that rather upset one's preconceived ideas on the subject. The question of eddies was very largely one of scale, and one could hardly conceive of the smaller eddies which went to form strato-cumulus clouds being comparable with the large convectional eddies which were associated with the larger cumulus and cumulo-nimbus. The effect described by Captain Meager rather suggested the smaller eddies which, one had always assumed, went to make up the strato-cumulus clouds, rather than the larger eddies.

Commenting on Sir Gilbert's reference, in the last paragraph of the paper, to the use of recording anemometers at gliding meetings, he said that although, as described by the lecturer, it appeared to be quite a simple matter, he doubted whether, in practice, it would be as simple as it appeared, because after all the gliding pilot depended very much on the cloud formations that he saw. That led him to recall Sir Gilbert's reference to the cells extending in some cases down to the ground and in other cases not so far down, and to ask whether there was anything in the appearance of the cloud, as seen from the ground, which would help the pilot to determine the extent of the vertical motion beneath it.

With regard to the reference, in the early part of the paper, to the roll-clouds which were described as vortices rotating in opposite directions, he said that sometimes, with transverse roll-clouds, one saw two rolls of clouds amalgamating into a single cloud, and he asked what was the nature of the motion in the single cloud when it was apparently formed by two vortices rotating in opposite directions.

Mr. DEWSBERY: Have the cells referred to by Sir Gilbert had a definite span of life? Did the temperature of the ground make any difference to the strength of the eddies?

Mr. THURSTAN JAMES: Would Sir Gilbert express any opinion regarding a novel theory recently advanced by the famous soaring pilot Herr Wolf Hirth? Herr Hirth had gained a great deal of experience regarding " thermals," that is to say, ascending currents of warm air which can be used for soaring as distinct from soaring in the currents beneath clouds.

Herr Hirth was satisfied that he had collected enough evidence to show that the rising air did not ascend in continuous columns, but in discontinuities and indeed masses of air seemed to get warmed up and then float away like bubbles. The effect was something like a stream of air bubbles rising in a tank of water.

Mr. BATEMAN: He was interested in the fact that at a certain velocity the roll of clouds was transverse to the normal flow and at a higher velocity the roll was longitudinal, and said that there may be an analogy between this effect and the laminar and turbulent flow of uniform air currents. He had been rather surprised to learn, however, that the photograph of the cloud shown in Fig. 19 was taken when the wind speed was low, and that turbulence was the reason why the rolls were no longer in straight lines. It seemed to him that there should be much less turbulence in a very light wind than in a high wind.

Referring to Sir Gilbert's analysis of the information obtained at Cardington (Fig. 26), he said that by using the circular cell method Sir Gilbert had obtained a sinuous curve for the change of velocity, and it did not follow the original curve, which showed very steep increase and gradual decrease of velocity. This discrepancy appeared to give more support to Mr. Durst's theory.

Sir GILBERT WALKER: In Fig. 26 the wind velocity curve had a steep upward gradient and a more gradual downward gradient. He did not understand the question.

Mr. BATEMAN: He gathered that Type II (*a*) was the curve assumed from the observations, and that Sir Gilbert's theoretical curve was given below in II (*d*); but this was sinuous and had not the steep increase of velocity.

Sir GILBERT WALKER: That was the curve of wind direction obtained when the cell did not pass overhead.

Mr. BATEMAN: Was a curve with a steep rise obtained if the cell passed directly overhead?

Sir GILBERT WALKER: Yes, as shown in curve (*a*), which was exactly reproduced by the cell.

Mr. SIMMONS (National Physical Laboratory): Had account been taken of the rotary motion in the cells? If one observed a vane, one found that in addition to a pitch change in the vertical direction there was also a change of yaw; indeed, a yaw meter record was very similar to a pitch record, *i.e.*, changes in the horizontal plane were very similar to changes in the vertical plane. Some experiments had been carried out at the National Physical Laboratory, using hot wires, which followed air changes very accurately; the hot wire anemometer would record changes of the order of 20 per second. Quite recently the experimenters there had trapped an eddy, which appeared to be rotating about a horizontal axis and had a diameter of about 40ft. All the details of that eddy were very well represented in the records, and he imagined that it was produced locally, either by trees or other obstacles. It would not be affected by the circular motion; but the change of motion in the horizontal plane had been observed also. Mr. Simmons asked if Sir Gilbert could give any information on this matter.

REPLY TO DISCUSSION

Replying to Mr. Durst's remarks, he would prefer to confine himself to the big issue rather than to discuss the details. Mr. Durst's interpretation was in terms of horseshoes. Horseshoes were easily produced in a laboratory when using liquids, but with air they were extraordinarily difficult to produce, although one observer had obtained something which bore a slight resemblance. However, Mr. Durst had not produced a photograph of horseshoes in the sky. Further, the photographs reproduced in the paper and exhibited at the meeting represented a perfectly random selection, and not a selection against horseshoes; yet there was not one to be seen in those photographs. Sir Gilbert added that he had a collection of at least 200 photographs of clouds, and he could produce only one which indicated something like horseshoes. He, personally, did not accept it as representing them, however, because the horseshoe pieces were outlying fragments. Therefore, he could say with some justice that horseshoes could not be regarded as occurring normally and as being the inevitable shape of the cells.

Commenting on the interpretation that the main up motion and down motion occurred close together, on the margins of the cells, Sir Gilbert said he had been particularly careful to draw attention to the way in which the vortices were situated. Wherever there were two in juxtaposition, they either ascended or descended together where they met. One could not make two columns of air run in opposite directions against each other without very special precautions, and if a theory demanded that the velocities should be in opposite directions in juxtaposition he would say that it was not in accordance with what he had observed in the sky or in the laboratory.

With regard to up-currents over the strato-cumulus, he said it had been noticed often that when one emerged from a cumulus cloud one was still in an up-current; he assumed, therefore—though in this he was making merely a hazardous guess—that the same situation arose above a strato-cumulus cloud. Mr. Entwistle was surprised, and naturally so, that there were indications of upward movement in the strato-cumulus as well as in the cumulus; part of the evidence for that was the report by Höhndorf, referred to in the paper, who had experienced the same kind of winds below the strato-cumulus as below the cumulus. But unfortunately the Memoir reproduced only a limited number of the ultra quick motion curves, so that it was rather difficult to say how far they were representative of normal conditions. If there had been another £10,000

available for this work, doubtless there would have been more of these curves, but it was not available, and one had to make the best of the information obtained.

The question as to the extent of vertical motion below clouds, and therefore the extent to which the cells extended below the clouds, was of great interest, and perhaps one could gain a certain amount of light in that regard. If one had in a laboratory a long straight cell containing a pair of vortices, then if the smoke occupied the area from top to bottom one would expect to get definite outlines of the vortices. But if in the sky the cell were 3,000ft. high, and the cloud occupied the top 500ft. of it, there would be vertical motion in the middle and descent at the side; but the cloud would only show the top of this motion. There would be, as in longitudinal or transverse cloud rolls, one long cloud above the ascending portion, perhaps curling round a little at the sides; and that was the sort of thing that usually occurred at cirrus level. One of the most characteristic clouds at cirrus level was the herring-bone—the long cloud with streamers at the sides. Sir Gilbert exhibited a photograph of transverse clouds, and said there was no suggestion of a division into two vortices; a cell was shown as a single band. The photograph showed more smoothness at the top of the band than at the bottom, which, he said, was simply a product of the dome shape he had alluded to, which again was what one would expect if one interpreted them as he did. If there were upward movement in a column and a cloud at the top of the column, the top of the cloud would be dome-shaped, and when one looked at it from one side the top edge would appear well defined while the bottom edge was fuzzy.

Sir Gilbert agreed with Mr. Entwistle that two vortices with motions in opposite directions could not join. He added, however, that two cells could join; the two right-handed vortices would join up, as also the two left-handed vortices. In the right-hand top corner of the photograph he had shown (Fig. 17) one could see the manner in which the division occurred, and each band was divided into two. Therefore, one could learn something as to the extent to which the cell motion persisted below the cloud by noticing whether the cloud was clean cut on both edges, in which case there was not much cell below it, or whether it was dome-shaped; in the latter case presumably the cell extended some distance.

The span of life of a cell was sometimes only three or four seconds, and sometimes it was half an hour. On this matter, however, he was unable to make any statement worth hearing.

As to the relation with the temperature of the ground, he said that though the type of the cells was in general connected with the wind velocity, it was the heating of the ground which largely produced the condition of general instability in which the cells formed. He would therefore expect eddies to be rather stronger on days when the ground was hot.

Dealing with Mr. James' question concerning thermal currents and the ascent of warm air in the form of a bubble, Sir Gilbert said that that represented in somewhat picturesque language the situation produced when ground was heated; there were thermal up-currents on a summer afternoon, and these would probably tend to occur in the form of cells. The question whether they were associated with clouds depended on the humidity conditions prevailing at the time.

With regard to the suggestion that turbulence should be smaller at low than at high velocities, he said that he knew so little about turbulence that it was difficult to express an opinion: but he imagined that with a given wind strength at ground level there might be a big variation in the amount of shear between two layers higher up, where meteorological factors came into play. It was pleasing to note that further progress was being made with the hot wire processes, and the evidence they would afford in relation to turbulence would be received with gratitude. All meteorologists realised that they were working on the fringe of a large realm about which they knew very little.

DURALUMIN APPLIED TO AIRCRAFT CONSTRUCTION

BY

W. H. LEWIS, B.Sc., A.C.G.I.

(Paper Read before the Students' Section.)

Introduction

The position to which aircraft construction has proceeded is due in a large measure to the intense metallurgical investigations of recent years. Amongst the materials that have arisen out of this are the light alloys of aluminium, and in particular, that known by the general name " duralumin." This alloy plays the part of main structural material in many of our present-day aircraft. The object of this paper is to give a brief general account of duralumin with reference to aircraft construction.

A Few Notes on Aluminium

Aluminium is the most abundant metal in the earth's crust, yet does not occur in the pure state. In fact, a condition of chemical purity is exceedingly difficult to obtain. Commercially pure aluminium, however, is produced on a large scale by electrolytic reduction of bauxite—an oxide of aluminium. During the reduction process quantities of iron (Fe) and silicon (Si), which were present in the raw material, are also reduced. Thus, most compounds of aluminium contain, as reduction impurities, some Fe and Si.

Aluminium itself is not a strong metal, so that it is somewhat confined to uses in which high mechanical strength is not essential—*e.g.*, electrical work. In the cast state it has a tensile strength of some $6\frac{1}{2}$ tons per square inch with a yield point at about $2\frac{1}{2}$ tons per square inch. By cold working, a tensile strength up to $12\frac{1}{2}$ tons per square inch can be obtained, accompanied by an elongation of 30 per cent.

With a specific gravity of 2.68 it stands out conspicuously amongst the metals—magnesium (Mg) excepted. Thus it was to be expected that an attempt would be made to achieve an alloy combining both the lightness of aluminium and the strength required in a structural material.

Composition of Duralumin

Table I gives the quantitative composition, together with values for ultimate tensile stress (U.T.S.); .1 per cent proof stress-tons per square inch and percentage elongation.

The figures for chemical composition indicate baldly the amounts of the constituents. They do not show their relationships, the one to the other, nor do they give any indication of the relation of combination to mechanical properties. For, whilst the constituents for bar, sheet and tube are nominally the same, the figures for U.T.S., .1 per cent. proof stress, and percentage elongation show considerable differences. These differences are due to the internal structure, and are, amongst other things, functions of temperature, time, and strain hardening.

TABLE I.

Constituents %–(Specfn. values)

Copper		3·5 - 4·5
Manganese		·4 – ·7
Magnesium		·4 – ·7
Iron	Impurities ≯ ·4	≯ ·75
Silicon	Impurities ≯ ·5	
Zinc		
Aluminium		The remainder

Strength figures–(Specfn values)

	Bar	Sheet	Tube
U.T.S	20 - 25	≮ 25	≮ 26
·1% proof	10 - 15	≮ 15	≮ 18
% elongn.	≮ 15	≮ 15	8 below 16G 12½ above 16G

At ordinary temperatures, copper (Cu), the largest alloying component, is taken into solid solution by aluminium to the extent of about .3 per cent.; whilst at 500°C., the amount increases to some 6 per cent. At a temperature about 550°C. Cu gives an eutectic with aluminium. At these elevated temperatures the Cu gives a compound represented by the formula $CuAl_2$, which is also taken into solid solution. During manufacture, or heat treatment, as the temperature gradually falls, the excess Cu comes out of solution and is deposited either within the solid solution crystals or as infilling between them in the compound, form $CuAl_2$. This disposition is, of course, dependent on the temperature and rate of cooling.

The magnesium combines with the silicon present as an impurity to form a stable silicide of magnesium, represented by the formula Mg_2Si. This compound behaves very much in the same manner as the Cu. With aluminium it enters into solid solution, and at a temperature of about 580°C. forms an eutectic.

The Fe and Si are considered as impurities, and it is usual to specify that they do not occur above certain amounts. Iron has a detrimental effect on an alloy to be heat treated. Silicon is, however, thought to be essential for effective age hardening.

Microscopic examination of cast duralumin shows the alloy to consist of large solid solution crystals, the interspaces being filled with eutectic containing both $CuAl_2$ and Mg_2Si. This structure gives some explanation of the inferior mechanical properties of the alloy in that state. When forged, this structure is broken down with consequent improvements in strength as represented by bar, sheet and tube in Table I. At the same time there is some loss in ductility. Thus, figures for strength and elongation are, to a certain extent, a measure of this structural breakdown. (It will be noted that for the lighter gauge tubes a small percentage elongation is called for.) Rolling and drawing to form plates and tubes further fines the structure.

Heat Treatment

Although strain hardening improves the mechanical properties, a much more effective control is obtained by applying heat treatment. The strength figures given in Table I are for the alloy in the fully heat treated condition. Simply, there are two conditions. One is said to render the alloy normal or fully heat treated. This is achieved by heating the alloy to some predetermined temperature and then cooling rapidly. When this treatment is complete, the optimum strength figures given are obtained. The other is the annealed condition; and is arrived at by heating to another predetermined temperature, and then cooling slowly and uniformly. The alloy is then permanently soft apart from any slight hardening which would be induced by working.

The Normalising or Fully Heat-Treating Process

The alloy is heated to about 485°C. and then quenched in water or oil. Attainment of this treatment temperature is essential if the full value of the process is to be obtained. At this temperature the Cu, its compound $CuAl_2$ and the magnesium compound Mg_2Si are in solid solution with aluminium. The object of quenching is to retain the internal structure in this state at ordinary temperatures. This condition is obtained, but only temporarily, as very soon after quenching, adjustments begin to take place, and the alloy is said to age harden. Immediately after the quench, that is, say, within the first hour, the alloy has mechanical properties which are little, if any, better than those pertaining to the annealed condition, and is perhaps easier to work.

Should, in the process of normalising, a temperature above 500°C. be employed there will be a tendency for large masses of the compound $CuAl_2$ to form, which remain after the ageing period has been completed. The alloy is then brittle, resembling the cast condition, and is ruined. Further, the metal has become soft so that loss of form may occur. To ensure that this condition is not attained, the upper temperature limit is generally taken as 490°C. Experience and examination have shown that the lowest temperature to which the alloy must be heated is in the vicinity of 475°C. To cover this, a lower temperature limit of 480°C. is worked to. Thus, with treatment temperature range of 480°C.-490°C., a matter of only 10°C., the necessity for rigid control of the process is apparent.

The conditions to be aimed at when quenching are a rapid and uniform cooling. As a quenching medium oil gives about the most uniform rate of cooling. Articles to be quenched in oil, however, must have been heated in a muffle furnace, not a salt bath as the latter leaves a film of salt rendering oil quenching dangerous. A more general medium employed is water. By providing a running supply of water an article can be quenched and washed of its salt at the same time. The actual temperature of the water is not important, but it should be such that at no time during the period steam is formed with consequent blanketing and uneven quenching. In the case of small parts, air quenching has been found satisfactory.

Age-Hardening

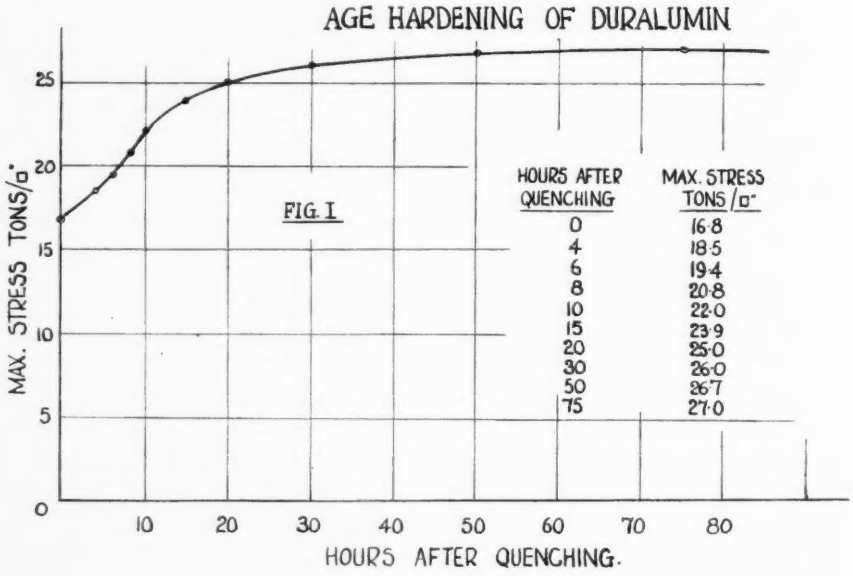
The adjustments in the chemical combinations of the alloy after quenching are a most important and useful feature of the normalising treatment. During the period that these changes are taking place the alloy is said to be age hardening.

It is considered that during this period breakdown of the internal structure occurs. The components Mg_2Si and $CuAl_2$ are precipitated from the solid solution to give a fine crystalline structure in a highly dispersed state. This process continues over a considerable period, commencing fairly rapidly and decreasing in rate with the passing of time. At the end of four days this may be, for all practical purposes, considered to have reached completion. Any further adjustments after this in a correctly treated article are, whilst being small from the point of view of strength values, of the nature of an improvement. The period can be reduced and the process accelerated by uniformly heating to a temperature not in excess of 150°C. without giving rise to any deleterious effects.

The curve (Fig. 1) illustrating the age hardening of duralumin indicates the kind of relationship that exists between maximum strength and time during the ageing period. At the end of 75 hours the maximum stress has risen from 16.8 tons per square inch to 27 tons per square inch, an increase of 10.2 tons per square inch. After a period of 15 hours has elapsed, *i.e.*, 20 per cent. of the above period, the increase has been from 16.8 tons per square inch, or nearly 70 per cent. of the whole.

The curves in Fig. 2—the age hardening curve has not been cross plotted from these—indicate the effects of both quenching temperature and time on the ultimate stress. This reaches a value above 27 tons per square inch for a quench at about 520°C. and a full ageing period. The value at 495°C. is comparable with that represented by the flat portion of the curve in Fig. 1. The effects of burning at temperatures above 520°C. on the strength figures are very apparent.

All the curves tend to a common value round about 350°C. and a change of curvature occurs. The value of the ultimate stress is here just above 16 tons per square inch—the same as that for the annealed alloy. This indicates that heating to 350°C. and quenching will have a negligible effect on the ultimate stress even after time has been allowed for ageing. With values of temperature below this the curves again rise. The ultimate stress is fairly well maintained up



to 200°C. From the figure it is evident that a temperature of at least 350°C. must be attained for effective annealing.

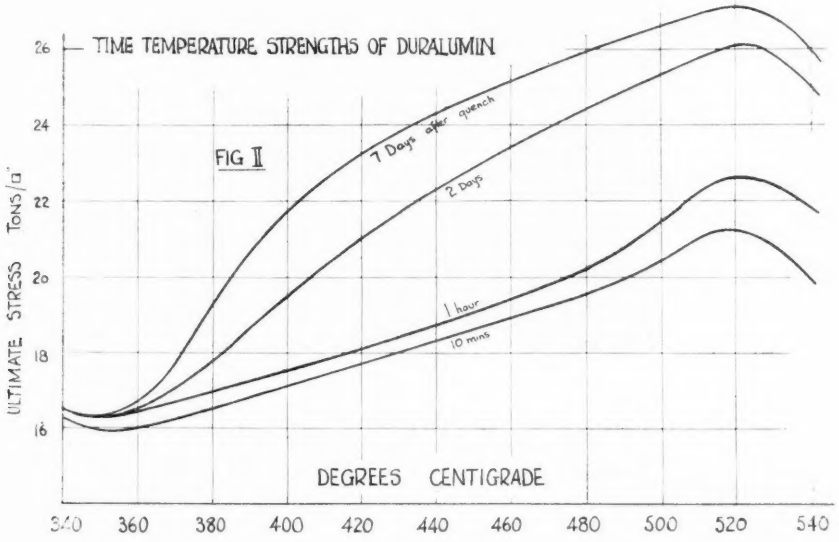
It is generally accepted that normalised duralumin can be safely cold worked within an hour after the quench; and this is made practical use of in manipulation of the alloy. Should it be necessary to do any further work on a part after the one hour period has elapsed further heat treatment should be applied. Such retreatment, if correctly carried out, will have no bad effects on the part. It is, however, inconvenient. In such a case annealing should be resorted to and the part normalised after all working has been done.

An important practical application of age hardening is the working of rivets into a structure. The rivets are normalised—a small quantity at a time—the usual way, then used within one hour of quenching. By adopting this procedure the heads can be formed free of cracks or other faults whilst in the soft state, after which they harden up and attain a similar condition to the surrounding structure. This is very convenient, more satisfactory and practicable than working rivets in the annealed condition and then normalising the compound part.

Annealing

After annealing the alloy is permanently soft. The effects of previous heat treatment and cold working are completely removed. An annealed part can, of course, be normalised in the usual manner. All extensive or protracted cold working should be done with the alloy in this condition, *i.e.*, annealed.

The lowest temperature to which the alloy must be heated in the annealing process is about 350°C.—as indicated in Fig. 2. By allowing the alloy to cool from this temperature, natural adjustments of the internal structure are able to occur. The upper temperature limit generally worked to is 390°C.—giving a range of 40°C. This, coupled with the fact that the upper limit is well below the incipient melting point—the alloy as a whole melts at about 650°C., whilst some of its constituents tend to in the vicinity of 550°C.—renders such a degree



of control as required in the normalising process unnecessary. Should the treatment temperature rise above 400°C. there is a definite tendency for the alloy to harden even though the rate of cooling is as slow as practicable. In fact, the chief difficulty of the process is obtaining a slow and uniform rate.

Methods of Heating

Upon the handling and the degree of control of the heat treatment processes depends the justification of the use of the alloy as an aircraft structural material. This is in a large part dependent on the method of heating employed.

There are some difficulties peculiar to the treatment of duralumin. One practice in treating steel is to introduce the metal into a furnace the temperature of which is well above that finally desired. The temperature of the furnace falls and that of the steel rises to the required value—by arrangement. For duralumin, the comparatively high temperature used in the normalising process renders such a procedure impracticable as serious overheating would be likely to occur. Further, it is desirable that direct heating should not be employed. With these restrictions uniform heating is less easy to attain. Another difficulty presents

itself in that the alloy does not give any visual indication of its temperature. It certainly becomes soft, a condition which may show itself, but is not useful. A means generally employed, and one which ensures some uniformity of heating, is the salt bath. Suitable salts have been found to be the nitrates of potassium and sodium. These are contained in a mild steel tank which can be conveniently heated by gas. Such a tank containing the fusion of molten salts is shown at A in Fig. 3, and is of such dimensions as to accommodate the largest sheet to be treated. Long strip is coiled before immersion. A number of balanced flap covers are provided at the top for convenience when dealing with small articles. A temperature recorder is affixed to the wall at B—one such should be sufficient, but needs regular calibration. In the foreground at C is the quenching bath—in this one water is used.

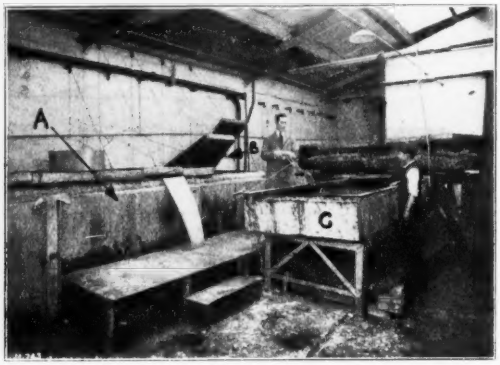


FIG. 3.
Salt bath.

Some of the disadvantages attendant upon this method are (*a*) the articles become coated with a film of salt which renders them liable to corrosion; (*b*) the operation is somewhat messy; (*c*) a drying operation may be necessary.

Another method involves the use of a muffle furnace. Such a furnace is one in which neither the fuel nor the products of combustion come into contact with the part heated. Apart from the difficulty of getting uniform heating, the method necessitates the use of at least three temperature recorders.

Corrosion

The word corrosion—a technical term synonymous with rust—has a fearsome sound. Rust does not condemn steel as a structural material, neither does corrosion in the case of duralumin. The problem of dealing with it is nevertheless acute, particularly in the case of marine aircraft.

Alloys having aluminium or magnesium as a base are inherently unstable. Thus, duralumin, given opportunity, corrodes fairly rapidly. There are two main types of corrosion—one arising from external conditions such as humidity or salt spray, and the other proceeding from within due to impurities. The former evidences itself as a white powdery adherent to the surface. Such an attack is shown in Fig. 4. The five plates have been subjected in a river to corrosive influences for varying periods. The action of the latter is more confined to the internal structure.

A prevalent cause of corrosion is the exposure to saline solutions such as salt spray to which marine aircraft are subjected or to the surface film incidental

to salt bath treatment. Alternate exposures to salt water and the atmosphere tend to produce a more severe action than does simple immersion. Dilute solutions appear to have a greater corrosive effect than concentrated ones. Also, annealed duralumin is more prone to corrosion than the normalised alloy.

The rate of corrosion is fairly high, that is a considerable quantity of corrosion product results from comparatively little action. This, together with the scattered nature of the product in the early stage, makes the attack appear more complete than it actually is. Early removal of the deposit and a thorough cleansing would leave the alloy little harmed except for surface appearance, and also a tendency to some brittleness.

The other type of corrosion—intercrystalline in nature—is of an electrolytic kind. That is, small differences of electric potential exist resulting in electro-

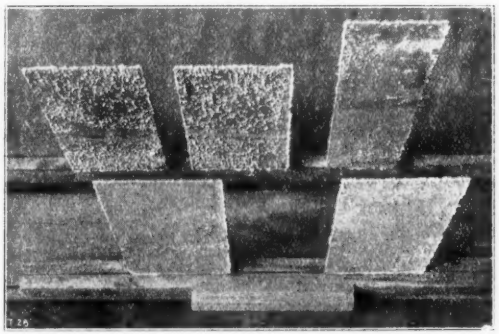


FIG. 4.
Corroded sheet.

chemical action. It may be due to impurities in the alloy itself; to the interaction of the alloy with some other metal in contact with it, or, less likely, to those conditions setting up surface corrosion. In some cases, particularly when it is due to internal impurities, this type is not detectable by mere surface inspection. The attack may be practically complete, and the plate broken by hand whilst from outward appearance it is normally sound. Generally, however, internal action is accompanied by pitting at the surface and so can be recognised. Thus, pitting is not an indication of surface corrosion only, and when it appears a thorough examination should be made.

Prevention of Corrosion

There is at present no method of treating duralumin so that its resistance to corrosion is complete. The cause of surface corrosion suggests one method of attacking the problem—that of coating the surface, so putting a barrier between it and the source of irritation. Varnishes and cellulose enamel have been used. A drawback to this is that protection is impaired if any of the coating becomes detached during handling.

A considerably more satisfactory result is obtained by subjecting the alloy to the anodic oxidation treatment. By means of this treatment a preventive film of oxide is formed on the surface, the process being an electrolytic one. The part to be treated becomes the anode whilst the cathode is of graphite. A solution of chromic acid CrO_3 is employed as the electrolyte. The period of treatment, which is the same for all articles, is one hour with a current density of three

amperes per square foot of total surface treated. The electrical pressure is varied during this period, reaching a maximum value of 50 volts.

In Fig. 5, D and E are two acid baths. Just above D can be seen the rail from which articles are suspended during treatment. The trough F in the foreground is for washing oxidised parts. The water enters continuously via the geyser at the left and leaves through a stand pipe at the further end.

Prior to oxidation, the surfaces have to be thoroughly cleaned from grease, salts, flux, etc. Welded parts should be in contact with boiling water for at least half an hour. Omission of these preliminaries may lead to surface pitting during the process.

To determine whether or not the treatment has been satisfactorily completed, several tests can be applied. A very simple one is to mark the surface with an

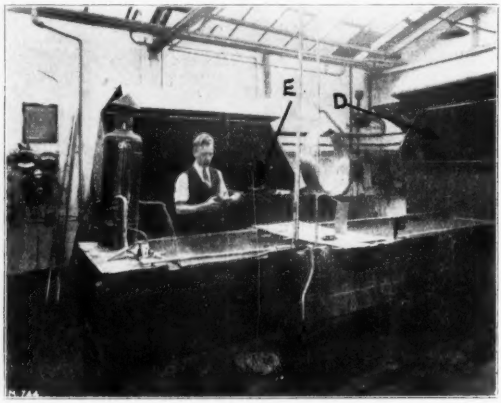


FIG. 5.
Anodic treatment plant.

indelible pencil and then attempt to remove it with a damp cloth. The mark cannot be taken out from a surface that has been properly coated. Another is to test the electric resistance of the film—sometimes referred to as the megga resistance test.

Usually, anodically treated parts are given a coating of varnish or enamel.

Alclad

An attempt to deal with the problem of corrosion in somewhat different manner has resulted in the production of the material known as alclad. Essentially, alclad is duralumin sheet sandwiched between aluminium. The protection afforded by the aluminium is a result of it being electro-negative to the alloy, giving an effect similar to the zinc on galvanised steel sheet.

The aluminium is not pure (commercially) as during the incidental heat treatment, a diffusion of the Cu and Mg_2Si components of the duralumin occur, which is not however detrimental. Alclad has proved itself to be considerably resistant to corrosion and has been used fairly extensively in American practice for some time. Recently it has been finding favour in this country and promises to be a very useful material. Anodic oxidation treatment has been advantageously applied to alclad.

The presence of the aluminium detracts from the mechanical properties of the whole as compared with duralumin itself. Although aluminium has a lower

specific gravity than duralumin the weights of geometrically equal pieces of alclad and duralumin differ little. Some figures have been quoted which indicate that the tensile strength of alclad is in the vicinity of 90 per cent. of that of duralumin.

The Value of Duralumin in an Aircraft Structure

Materials used for main structural parts are steels, duralumin—here alclad is implied where suitable—and wood. For various reasons the use of wood persists, but generally for large or high performance craft, metal construction is invariably adopted. It is, then, steel versus duralumin.

STRENGTH-WEIGHT COMPARISON

Specific gravity duralumin 2·85, Specific gravity steel 7·8

TABLE II — DIRECT TENSION & COMPRESSION

	f_t	$f_t/s.g$	f_c	$f_c/s.g$
DURAL T4	24	8·43	18	6·32
STEEL T5	45	5·77	37·5	4·81

Members having identical geometrical characteristics.

Dural equal to a steel with $f_t = 45 \times \frac{8.43}{5.77} = \underline{65.7 \text{ tns/a}''}$

Dural equal to a steel with $f_c = 37.5 \times \frac{6.32}{5.77} = \underline{49.2 \text{ tns/a}''}$

TABLE III — SIMPLE PIN-JOINTED STRUTS

	DURAL T4		STEEL T5	
L/K	f_c	$f_c/s.g$	f_c	$f_c/s.g.$
30·2	14·3	5·01	30·2	3·88
102	4	1·40	10·9	1·40

Members having identical geometrical characteristics.

Dural better than steel T5 (or any other steel having a lower yield figure than T5) for values of $L/K < 102$

TABLE IV — TORSIONAL SHEAR

	DURAL T4		STEEL T5	
D/t	f_s	$f_s/s.g.$	f_s	$f_s/s.g$
20	12·55	4·4	26·1	3·35
30	10·2	3·58	23·5	3·02

Members having identical geometrical characteristics.

Dural better than steel T5 (or any other steels with lesser strength figures) but relatively less so as the value of D/t increases.

A comparison between these on a strength basis will give some indication of the merits of the alloy. Such a comparison is not complete, but it is doubtful whether full account of the variations could be included. Considerations—apart from the peculiarities of any particular job—of supply, cost and amount of material carried in stores, amongst other things, enter to make the question indeterminate.

The figures for the strength—weight comparison are self-explanatory. The tensile strength is represented by ft, the compressive strength by fc, and the torsional shear strength by fs. Pin centre length divided by radius of gyration and diameter thickness ratio are denoted by L/K and D/t respectively.

Any particular member has to be considered on its merits apart from strength values. Generally, it can be taken that certain principal dimensions are predetermined; thus, the comparisons have been made with members having identical

or geometrically similar characteristics. The tubular form and the specification T_5 have been used for convenience and simplicity.

In the stiffness—weight comparison—E is Young's modulus of elasticity and C the shear modulus. Deflections are represented by δ.

The figures show that not only does the specific gravity (S.G.) enter into the comparison, but also the elastic constants of the materials. Thus, the values for strength and stiffness for duralumin cannot be multiplied by the ratio S.G. steel divided by S.G. duralumin, *i.e.*, by 2.74 to give equivalent steel values.

The foregoing comparisons give a crude theoretical indication of the value of the alloy. The extent to which it is employed is a practical and perhaps more convincing demonstration.

STIFFNESS - WEIGHT COMPARISON.

E Duralumin $10{\cdot}5 \times 10^6$ lbs/a" E Steel 30×10^6 lbs/a"
C Duralumin 4×10^6 lbs/a" C Steel 12×10^6 lbs/a"

BENDING FLEXURE

Deflection $\delta \propto \frac{WL^3}{EI}$

i.e. $\propto \frac{1}{E}$ Members having similar geometrical characteristics.

$\delta_{dural} \propto \frac{1}{10{\cdot}5 \times 10^6}$ | $\delta_{steel} \propto \frac{1}{30 \times 10^6}$

$\delta \times S.G. \propto \frac{2{\cdot}85}{10{\cdot}5 \times 10^6}$ | $\delta \times S.G. \propto \frac{7{\cdot}8}{30 \times 10^6}$

i.e. $\propto {\cdot}271 \times 10^{-6}$ | i.e. $\propto {\cdot}26 \times 10^{-6}$

Assuming the allowable f_c for dural to be 18 tns/a" then,
dural is as stiff as a steel with allowable $f_c = 18 \times \frac{{\cdot}26 \times 30}{{\cdot}271 \times 10{\cdot}5} = \underline{49{\cdot}4 \text{ tns/a"}}$

TORSIONAL FLEXURE

Deflection $i \propto \frac{TL}{CI}$

i.e. $\propto \frac{1}{C}$ Members having similar geometrical characteristics.

$i_{dural} \propto \frac{1}{4 \times 10^6}$ | $i_{steel} \propto \frac{1}{12 \times 10^6}$

$i \times S.G. \propto \frac{2{\cdot}85}{4 \times 10^6}$ | $i \times S.G. \propto \frac{7{\cdot}8}{12 \times 10^6}$

i.e. $\propto {\cdot}713 \times 10^{-6}$ | i.e. $\propto {\cdot}65 \times 10^{-6}$

Assuming the allowable torsional f_s for dural to be 12·55 tns/a" then,
dural is as stiff as a steel with allowable $f_s = 12{\cdot}55 \times \frac{{\cdot}65 \times 12}{{\cdot}713 \times 4} = \underline{34{\cdot}3 \text{ tns/a"}}$

The first all-metal aeroplane constructed in this country was the "Short" Silver Streak, which appeared in 1919. In this machine duralumin predominated. From that time the alloy has had a definite place in an air frame.

Apart from the obvious attractions of its low specific gravity it makes a further appeal to the constructor in that it is easy to manipulate—bending, pressing, spinning and general machining offering little difficulty. The supply is plentiful and it can be obtained in all useful forms.

Perhaps the most useful is sheet and strip. As such it is employed in the construction of plane spars, wing covering, fuselages, hulls, floats, engine nacelles, etc. Its particular value in hulls is that the necessary planing bottom thicknesses can be obtained with a minimum of weight, as also can the stiffness of frames. Owing to its easy manipulation it is possible to build up particularly efficient spar sections from the consideration of stress developed. As a tube it is found in braced structures generally. It has a special place in plane ribs or formers where sizes are often determined by values of L/K.

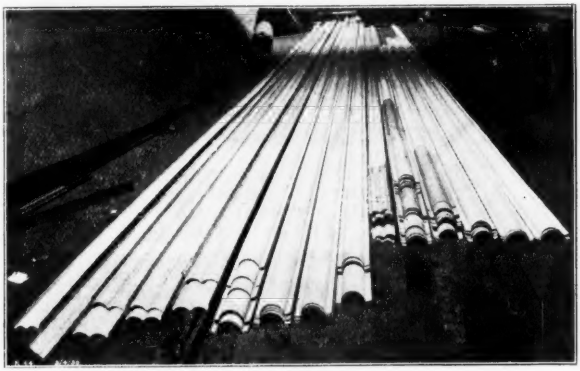


FIG. 6.
Spar strip.

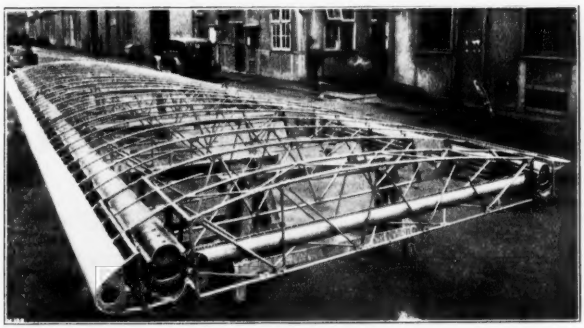


FIG. 7.
Uncovered main plane.

Other conditions are less useful structurally. The most important application of the forged alloy is to airscrews. In the cast condition it is only used in lightly or unstressed parts, or where appearance is a consideration. Heat treatment having little effect on the coarse crystalline structure, it has inferior strength values. For this reason, welding of duralumin is not satisfactory for aircraft construction—the alloy in the vicinity of the weld being reduced to the cast condition.

I have been able to give some illustrative pictures. Fig. 6 shows some duralumin spar strips which are pressed to shape. An uncovered main plane is

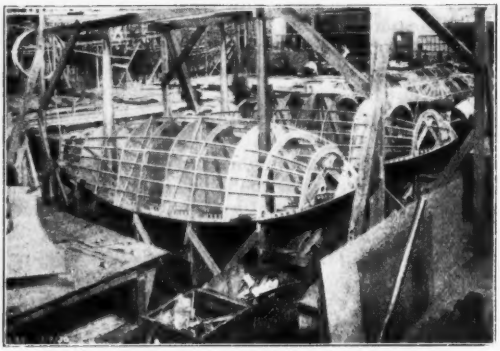


FIG. 8.
Floats in construction.

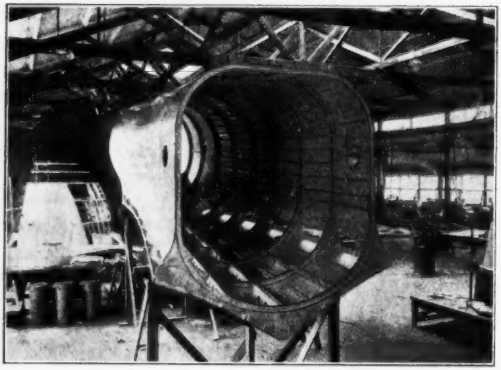


FIG. 9.
Portion of a hull.

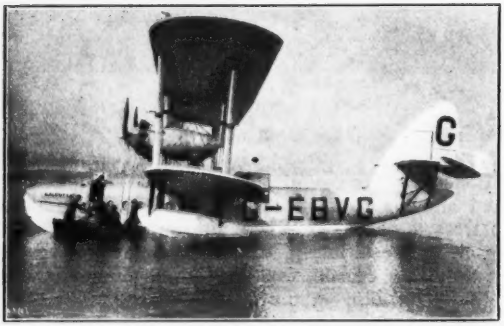


FIG. 10.
"Calcutta" on river.

seen in Fig. 7. This gives a good idea of its general use in spar and rib construction. Figs. 8 and 9 show wing-tip floats and a hull in the course of construction. A completed boat is seen on the river in Fig. 10.

In Conclusion

In spite of its wide use in the aircraft industry, duralumin is practically a newcomer to structural engineering. One development which has perhaps somewhat kept it in the background is the application of stainless steel. It is reasonable to suppose that the possibilities of aluminium alloys have not yet been fully appreciated so that steel may have to give them further place. A serious deterrent to its use is the tendency to corrode. No doubt, as with steel, a solution will be supplied to this difficulty and so further widen its employment.

SOME NOTES ON THE PRESSURE PIPING EFFECTS ON FUEL INJECTION

BY

C. W. LAWSON, B.Sc.(Eng.)

(Paper Read before the Students' Section.)

During the last few years the use of the Diesel engine for aircraft has become important; it has advantages and some disadvantages when compared with the petrol engine, and what we are directly concerned with is overcoming, or at least reducing, the disadvantages. The most obvious of these is the relatively high weight-power ratio of the engine, but it is to be hoped that this will be overcome as rapidly as it was in the development of the petrol engine. In any case, the unfavourable weight-power ratio of the compression-ignition engine is, for long flights, offset by the weight of fuel required to be carried.

One way of improving the weight-power ratio is to aim at a still greater efficiency of burning of the fuel. The effects of turbulence, and more especially, of orderly swirl of the charge of air in the cylinder has been shown, by our most successful engine designers, to exert a very great influence on the efficiency of combustion. Coupled with this, however, it is important that the fuel should be injected in the correct way so as to ensure a best rate of combustion. As an extreme example, it is not good practice, whatever the state of turbulence in the cylinder, to inject the bulk of the fuel before combustion starts, or to allow injection to proceed until exhaust takes place. The rate and efficiency of combustion also seem to be influenced by the amount of atomisation and penetration of the fuel spray.

The most usual method of injection of fuel into the cylinder is by means of a small plunger pump connected to an atomiser or nozzle which incorporates a valve. This injection valve is opened against a spring by a predetermined minimum pressure in the fuel pipe, and it positively closes when the pressure in the fuel pipe falls below a value also determined by the strength of the spring operating the valve. With this type of valve, therefore, we have a sudden beginning and end to injection without any dripping from the nozzle after the end of injection. The other type of injection nozzle has no such valve, so after injection should have ceased the pipe will still be under pressure as in the case when using the injection valve. Since there will be nothing but the gas pressure in the cylinder to prevent the oil in the pipe expanding and the pipe contracting due to elasticity, a kind of dribble from the nozzle is to be expected; this dribble will be accentuated by a falling cylinder pressure. In spite of this apparent disadvantage, the open nozzle has been used with success by at least one firm making aero engines, namely, Junkers of Germany. It is true that the orderly swirl used in the engine cylinders may offset the possible disadvantage of this type of fuel injection. This engine operates on the two-stroke cycle and has a high valve efficiency which can be compared with that of the sleeve valve engine, also very small capacity fuel pipes are used, thus reducing the amount of expansion of oil through the open nozzles after injection should have ceased.

I recently had the opportunity of using a piece of apparatus, which, for lack of a better name, has been called an injection meter. Details of the design of this

injection meter are not at present available for publication. However, it may be said that the meter measures the quantity of oil delivered by a nozzle, which may be open or spring-loaded, for every degree of cam turning during pump delivery. Experiments on pumps, using this meter, must be carried out independently of the engine, which is rather to be regretted. It is highly desirable to place a curve, showing rate of injection, directly on to an engine indicator curve, to see the effects of variations.

In order that the measurement of oil delivered may take place at the same point in each of a series of delivery cycles, the pump camshaft and injection meter shaft must be geared together without any backlash in the gearing, while at the same time it must be possible to change the relative angle of the two shafts. This was made possible by means of a special coupling situated between the pump camshaft and the meter shaft. A scale of degrees on the coupling enables the necessary adjustments to be made for measuring the rate of delivery from the pump at any part of the cycle. Fig. 1 shows the arrangement of the coupling;

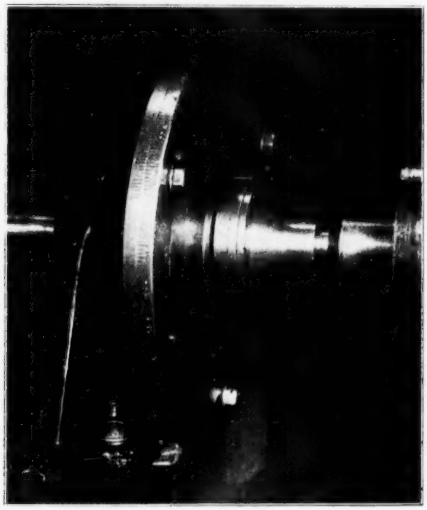


FIG. 1.

three bolts were used to lock the two parts of the coupling together, adjustment being made when the bolts were slackened. The disadvantage was that it was necessary to stop the apparatus to make the adjustment, but if a differential gear is used the frequent stoppages are rendered unnecessary.

The pump and injection meter were driven by an electric motor wired with suitable resistances to give a good speed variation and control. A revolution counter was fitted to the meter shaft so that the number of revolutions could be measured when necessary, and a tachometer was used to obtain some idea of the speed.

For the tests to be described an experimental nozzle was constructed which is shown in Fig. 2. The nozzle itself is made interchangeable with other similar nozzles; by removing the nut (*f*) the nozzle (*e*) may be removed and replaced by another as required. The figure also shows the method used for making the joints at the ends of the pipes; a small flange (*d*) is screwed on piping (*b*) so that the end can be seated by tightening the nut (*c*) which is provided for that purpose.

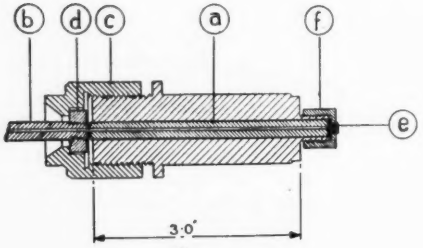


FIG. 2.
Experimental nozzle.

The pump used for most of the tests to be described, was one borrowed from a single cylinder opposed piston engine which was not in use at the time. The pump is designed for use with the open type nozzle fitted to the engine, and works on the well-known principle used by Bosch. The cam driving the plunger gives an approximately constant velocity during the injection period.

To find the accuracy to which the readings could be repeated, the same test was carried out six times and the readings are shown in Fig. 3. The vertical scale is " quantity of oil delivered per degree of camshaft rotation," and the base is " camshaft degrees." The widest variations of the measurement of quantity delivered occur where the curve is steepest. A small error in setting the

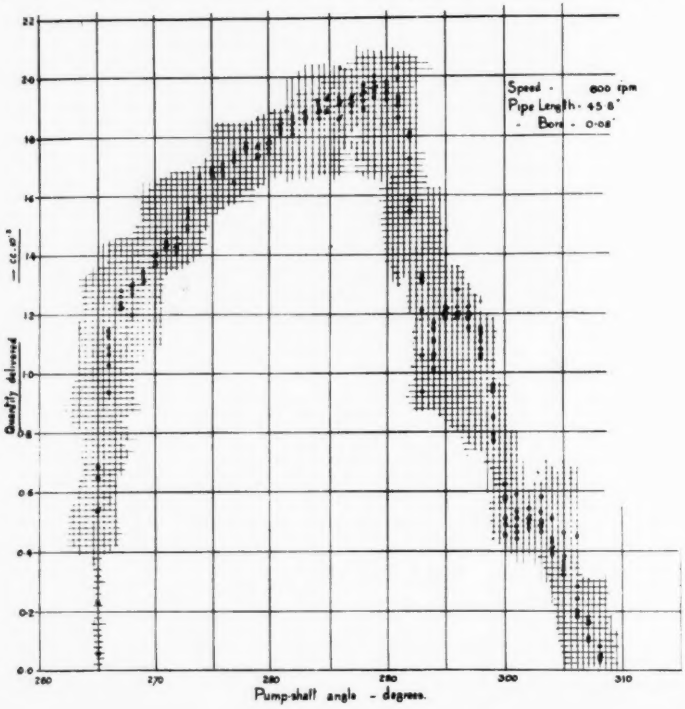


FIG. 3.

angle or a slightly high or low mean speed will cause the quantity measured to be displaced along the curve slightly, and owing to the rapid rate of pressure change where the curve is steep, the small angle or speed error will cause a large apparent error in quantity. Where the pressure is fairly constant, the variations seen in the figure are taken as wholly due to errors in measuring the quantity of oil delivered by the nozzle; this error amounts to not more than four per cent.

As regards the efficiency with which the apparatus will measure the quantity of oil degree by degree at various speeds. A measuring apparatus seen in Fig. 4

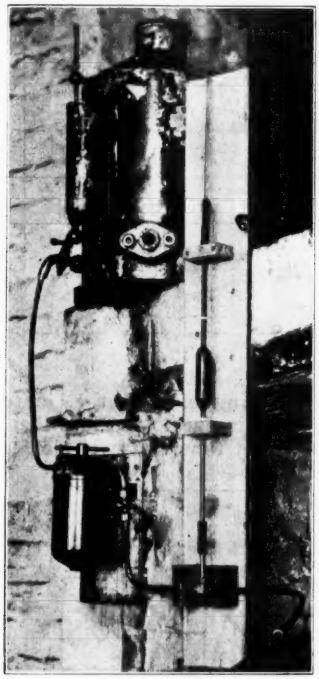


FIG. 4.

was used to measure the rate of use of oil by the pump; oil normally passes from the tank and through the filter to the pump, but if the cock between the filter and the vertical glass tube is closed, the supply of oil must now come from the glass tube. The tube was calibrated, so that by measuring the time for the level to fall between the calibrated marks the rate of flow of oil can be found. From readings of the rate of flow of oil to the pump, the amount used per pump cycle was calculated and plotted in Fig. 5. The sum of the quantities measured during each degree of the pump cycle was found and plotted on the same diagram. These quantities are shown for the whole range of speeds used. The greatest discrepancy seems to be about five per cent. at the lowest speed; here the sum of the quantities measured at each degree is greater than the quantity supplied to the apparatus. At higher speeds, however, we find a somewhat smaller amount measured per cycle than is supplied to the pump. A correction can, therefore, be easily applied to the readings at any speed in the range used.

Readings were taken, using the same pump, at various speeds. These are plotted in Fig. 6 as quantity delivered in cubic centimetres per degree of pumpshaft rotation, on a base of pumpshaft angle; the areas of these curves are therefore proportional to the quantities delivered per pump cycle. As might be

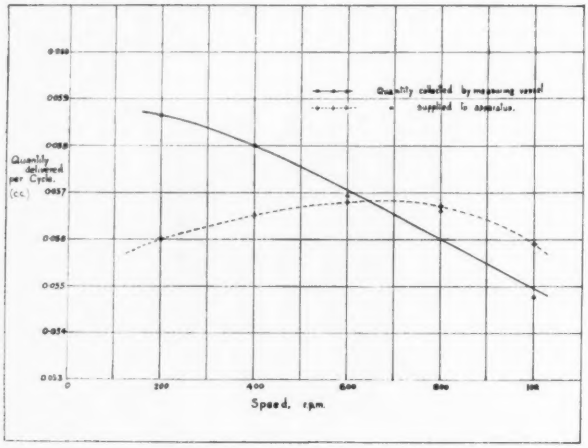


FIG. 5.

expected, the lag of the beginning of discharge, in terms of camshaft angle, increases with the speed. This is due to the fact that the rise of pressure set up by the pump takes a constant time to travel along the pipe, irrespective of

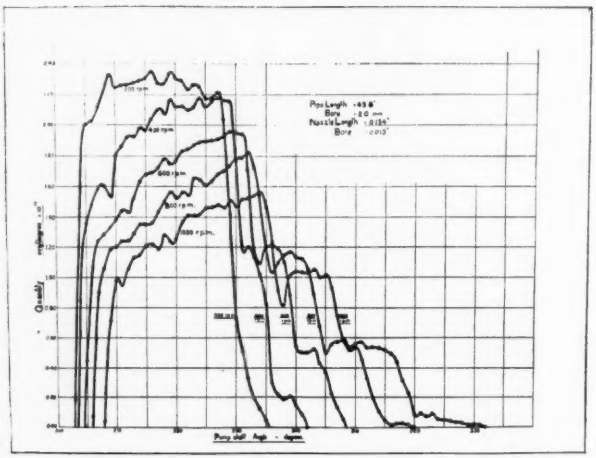


FIG. 6.

the speed at which the pump is running. These curves also show how the amount of dribble is influenced by the speed; discharge from the pump takes place through the same angle at each speed, but at the higher speeds the discharge from the nozzle takes place through a greater angle on account of the excessive dribble.

The readings plotted in Fig. 6 are plotted to different scales in Fig. 7. This figure shows " rate of discharge " in cubic centimetres per second, on a base of time, and as in the previous diagram, the areas are proportional to the amount

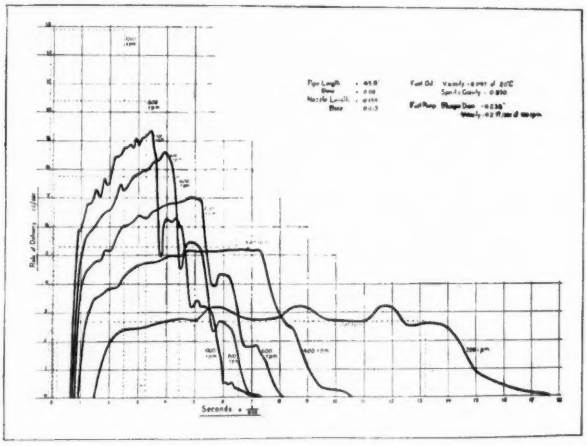


FIG. 7.

delivered per cycle. The dotted lines indicate what should be happening at the pump, assuming instantaneous beginning and end to delivery and that the speed of the pump plunger is constant. The rate of discharge from the nozzle is nearly

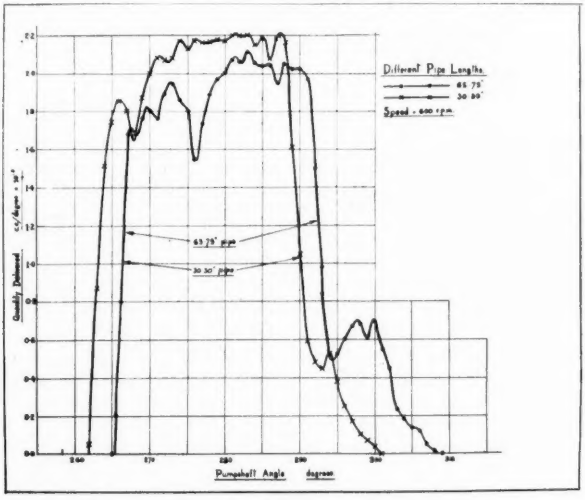


FIG. 8.

proportional to the square root of the pressure, so these curves represent pressures to a scale which can be found from a knowledge of the coefficient of discharge of the nozzle. Another point to be noted in connection with these curves

is the constant frequency of the pressure fluctuations at all the speeds used; the pressure fluctuations are assumed to be due to a single pressure impulse which starts at the pump and is reflected backwards and forwards along the pipe. The frequency of the pressure oscillations is, therefore, dependent on the pipe length and on the speed of propagation of the pressure impulse.

The influence of pipe length on injection lag is shown in Fig. 8 for two pipe lengths. This " lag " is the time taken between the beginning of delivery by the pump and the beginning of injection from the nozzle. The lag is shown in the figure in terms of camshaft angle, the speed at which these readings were made being 600 r.p.m. and the pipe lengths were 30.0in. and 65.75in. The speed of the pressure impulses influencing injection can be shown to be equal to the speed of sound in " the oil in the pipe," but the injection lag appears to differ from this speed by a small amount. The pipe length has some influence on the maximum pressures, and as is to be expected, a long pipe gives a lower pressure than a short pipe, but the amount of dribble is greater with a longer pipe.

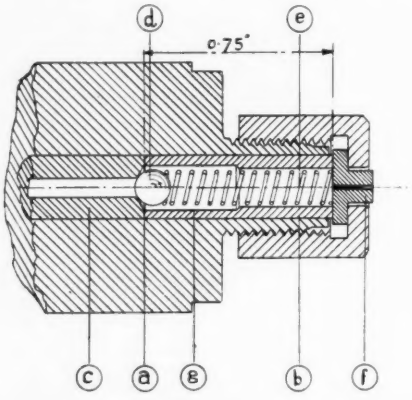


FIG. 9.

Arrangement was made to find if the position of the non-return valve in the delivery pipe had any effect on the amount of dribble. Fig. 9 shows the experimental nozzle fitted with a non-return ball valve loaded with a light spring. Readings were made with two pipe lengths, 45.8in. and 89.3in.; first, with the non-return in its normal place at the pump, and second, with the non-return valve at the nozzle; all the readings being made at a speed of 600 r.p.m. These curves are shown in Fig. 10, and in accordance with the remarks on Fig. 8, the longer pipe shows a later discharge than the shorter pipe. The broken lines indicate the conditions when the non-return was at the nozzle, and the full lines show the effect of replacing it by the non-return valve at the pump. Somewhat higher pressures were recorded with the valve at the nozzle, but in this case there was a slightly smaller total discharge from the nozzle. This effect is probably due to the negative pressure wave which is set up when the pressure in the pump falls suddenly and causes a small amount of oil to flow back. With the valve at the nozzle, once the discharge had ceased, no dribble was found to occur when the reflected wave should have returned to the nozzle. It is very likely that the opening of the port release in the pump caused the reflected pressure wave to be damped out very quickly.

All the readings have been made in terms of the amount or rate of delivery from the nozzle, and it is desirable to know how the rate of delivery is connected with the pressure behind the nozzle; it was therefore decided to find the co-

efficient of the nozzle. A hydraulic testing machine using oil was available, but with the very viscous oil in use in the machine, a sufficient pressure could not be obtained to produce the required rate of flow through the nozzle. For measuring the pressure an ordinary Bourdon gauge was used after trying a dead weight gauge shown in Fig. 11. This gauge was found unsatisfactory when used with water owing to the lack of suitable lubrication. A coefficient of discharge was found which at first increased with pressure and then became fairly constant over the greater range of pressures used. It was found to rise from 0.52 at about 40lb./sq. in. to 0.86 at 140lb./sq. in. and 0.87 at above 600lb./sq. in. This gives a maximum pressure used for the tests of about 1,200lb./sq. in.; it is lower than the pressures commonly used in engines, but the pump was designed for nozzles giving about a quarter the discharge of the nozzle used. This also seems

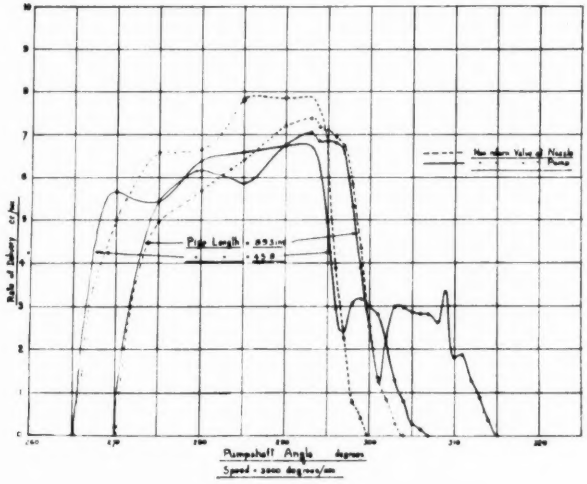


FIG. 10.

to indicate that with higher pressures, due to the use of a smaller nozzle, the dribble would be proportionally larger with the total discharge about the same. However, the effect of the falling gas pressure in the cylinder during the expansion stroke in increasing the dribble is smaller the higher the fuel injection pressure. With a lightly loaded non-return valve at the nozzle only, as soon as the pipe pressure has fallen to that in the engine cylinder, the valve will close, due to the gas pressure, and any unexpanded oil in the pipe will return to the pump. Another method of relieving the pressure in the pipe at the end of delivery is by means of the Bosch pump outlet valve; it has a conical seating and a stem on which a ring forms a piston in the fuel delivery passage. Before delivery can occur the oil pressure must raise the piston above the seating; when the pressure in the pump falls, a spring returns the valve to its seating, and in doing so the volume of oil under pressure in the pipe will be increased by an amount equal to the volume displaced by the part of the valve stem forming the piston.

In order to exaggerate the pipe effects in the foregoing experiments, long pipes of fairly large volume were used. The following points are indicated by the results:—

The amount of dribble is influenced by:—

1. The volume of the pipe.
2. The maximum pressure which is determined by the pump speed and the resistance through the nozzle.

3. The position of the non-return valve in the delivery pipe seems to direct the flow of oil to one end of the pipe or the other after the pressure in the pump has been released; the oil either issues from the nozzle in the form of dribble or returns to the pump.

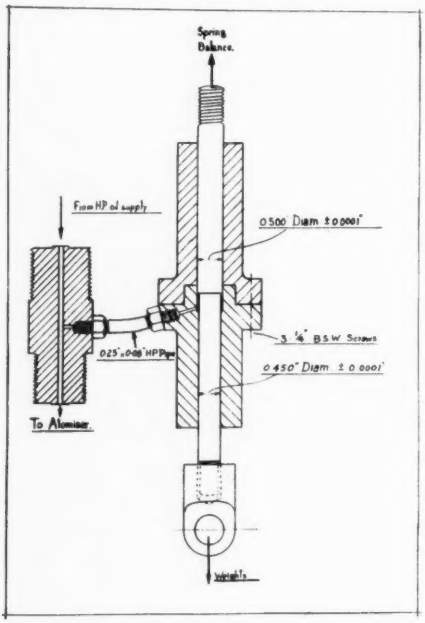


FIG. 11.

The injection lag, or the time taken between the beginning of pumping and the beginning of injection:—

1. Depends to a small extent on the pump speed (Fig. 7).
2. Is proportional to the pipe length.
3. It is found to bear some relation to the time taken by a sound wave to travel along the pipe; the theoretical time taken for a sound wave to travel along one foot of oil in a pipe is about 0.0002 second, the speed of sound being about 5,000 feet per second. The speed at which the pump is running seems to affect the condition of the oil in the pipe and so alters the speed of the initial wave. The injection lag may become important at high speeds when different pipe lengths are used on the same engine.

The loaded injection valve and the open nozzle each have their advantages, though the injection valve seems to be better for general purposes, but it is more complicated and is probably more liable to trouble. The open nozzle is simple to construct, but with it injection is less easy to control, and for satisfactory results special consideration must be given to the design of the engine in order to produce the best conditions for combustion.

Unfortunately, from the point of view of making this work complete, it has not yet been possible to examine the effects of nozzle area, cam design, and the effects of considerably higher speeds than have been used.

ON A NEW AIRCRAFT-SEXTANT FOR USE WITH VISIBLE HORIZON*

BY

L. BECKER, Ph.D.,

Regius Professor of Astronomy in the University of Glasgow.

1. When this instrument is in its observing position the visible horizon is reflected at three points vertically downwards into a telescope. The portions of the horizon observed are facing the observer and lie 60° to his right and left. The images of the visible horizon appear as three straight lines in the field of view intersecting at about 60°. The observation consists in bringing the image of the celestial object into a certain point defined by the configuration of the horizon-lines. It is of no consequence whether all the rays after the downward reflection are again reflected into a horizontal direction, and whether this occurs before or after the rays enter the object-glass. It will be shown below how the observer is enabled to keep the error of inclination so small that its effect on the result, of second order, can be neglected.

2. *Description of Instrument.*—The frame of the instrument, similar to that of a sextant, supports a right-angled prism as index-mirror whose position can be read on a divided circle. The telescope points to the index-prism and may be detachable. A glass plate is firmly fixed on the frame between object-glass and index-prism at about right angles to the telescope, and carries, cemented to it, three reflecting prisms 60° apart from each other. They are right-angled, the angle at the plate not being quite 45°, and are so arranged that light propagated parallel to the plate towards the prisms is reflected into the telescope. For convenience of observing, the eye-end of the telescope may be at right angles to the optical axis. In accordance with § 1 a right-angled prism may be substituted for the plate, and the telescope may lie in a horizontal direction when the instrument is in the observing position (Fig. 5).

3. *Theory.*—Let all the directions entering the discussion be displaced parallel to themselves to the centre of a sphere so that the intersections with the sphere represent the directions. In the diagram, A_1A_2 represents the plane of the glass plate, which serves as reference plane. Its pole, M, would stand for the optical axis of the telescope if this were perpendicular to the glass plate. Q_1 on MA_1 stands for the normal to the middle mirror, and Q_2 on MA_2 for the normal to the mirror facing the horizon towards the left. The angle enclosed between the edges of these mirrors, here about 60°, is ϕ_2, and is represented by the arc A_1A_2. The arcs MQ_1 and MQ_2 are respectively $45^\circ - c_1$ and $45^\circ - c_2$, and designate the inclinations of these mirrors to the glass plate. Similarly, the pole Q_3 of the third mirror is situated behind the plane of drawing, and its position is given by ϕ_3 and c_3.

I assume that the instrument has been adjusted in the same manner as a sextant, the middle mirror replacing the horizon-glass; then the plane of the circle is also represented by the great circle MA_1, and the normal, I, to the index-glass moves on this great circle. Let R_0 be the circle-reading when I lies in Q_1,

* Reprinted from the *Monthly Notices of the Royal Astronomical Society* (January, 1933, Vol. 93, No. 3) by courtesy of the Council.

i.e., when there is coincidence of the two images of a distant object due to rays reflected by index-glass and middle mirror (as in the ordinary sextant). Let an object, S, be taken under observation while the plane of the circle is held vertically, whereby both S and the zenith, Z, lie on the great circle MQ_1I. Errors arising from an inclined position of the plane of the instrument, or from maladjustment, have the same effect as with an ordinary sextant and need not be considered here. With these reservations, the astronomical horizon, H_1H_2, intersects the reference great circle, A_1A_2, at a point 90° from A_1 and H_1. Hence $A_1H_1=i$, $A_2H_2=i\cos\phi_2$, if i designates the inclination of the glass plate to the astronomical horizon. The visible horizon is represented by a small circle, K_1K_2, parallel to H_1H_2, at angular distance D, the dip of the horizon.

The astronomical and visible horizons intersect the great circle MQ_1 at right angles in H_1 and K_1 respectively. The images of the points A_1, H_1, K_1 as reflected by Q_1 lie respectively equidistant from Q_1, and their relative positions are shown in Fig. 2 on the assumption that D is less than $2c_1$. In this diagram $MA_1'=2c_1$, $A_1'H_1'=i$, $H_1'K_1'=D$, and the visible horizon intersects MH_1' in K_1' at right angles.

Similarly, the astronomical and visible horizons intersect the great circle MQ_2 at H_2 and K_2 at an angle $(90°-i\sin\phi_2)$. The images of the points A_2, H_2, K_2 as reflected by Q_2 are designated by dashes and marked in the diagram. $MA_2'=2c_2$, $A_2'H_2'=i\cos\phi_2$, $H_2'K_2'=D$, and the image of the visible horizon intersects MK_2' in K_2' at an angle $(90°-i\sin\phi_2)$.

The images reflected by the third mirror are shown with suffix 3 in the figure.

If the eye-piece were placed in the optical axis of the telescope, Fig. 2 would give the relative positions of the images with M as centre of the field of view. Nothing is changed in this configuration by a reflection common to all the rays, *e.g.*, near the eye-end in a periscopic telescope, or, before entering the telescope, by a right-angled prism whose hypotenuse lies about parallel to the middle prism. Only three lines of the visible horizon are perceptible. The left and right horizon-lines intersect at a point designated by X.

(*a*) Let the Image of the object, S, be brought into coincidence with point X by turning the normal, I, to the index-prism from Q_1 to I_x, in which position the reading is R_x; then $Q_1I_x=\frac{1}{2}(R_x-R_0)$, provided that the figures on the circle are doubled. The astronomical altitude of S is $h=SH_1=SI_x-H_1I_x$. Substitute $H_1I_x=H_1Q_1-I_xQ_1$, and $H_1Q_1=Q_1H_1'$, $SI_x=I_xX$, and obtain

$$h=R_x-R_0+\delta R_x, \text{ where } \delta R_x=XH_1'.$$

To find XH_1', measure $XK_1=s$ (see below), then $XH_1'=s+D$. Further, $XH_1'=MH_1'-MX$ and $MH_1'=i+2c_1$; hence $+2c_1-s-D=MX-i$. From this I obtain an expression for D in terms of s, i, c and ϕ in the following way.

Let $K_2'X$ intersect MH_1' at X_2. MX_2 in triangle $MK_2'X_2$ may be calculated from $MK_2'=2c_2+i\cos\phi_2-D$, the angle ϕ_2 at M, and the angle $(90°+i\sin\phi_2)$ at K_2'. In the same way let $K_3'X$ intersect MH_1' at X_3, then MX_3 may be calculated in an analogous way. Both combined give

$$MX-i=\frac{2c_2\sin\phi_3+2c_3\sin\phi_2-D(\sin\phi_2+\sin\phi_3)}{\sin(\phi_2+\phi_3)}$$

The second-order terms which contain i^2, iD and ic have been omitted. Note that the expression for D in terms of s, c and i (which is not put down here) does not contain the first power of the inclination i.

$$\delta R_x=\frac{s(\sin\phi_2+\sin\phi_3)-2c_1\,.\,\sin(\phi_2+\phi_3)+2c_2\sin\phi_3+2c_3\sin\phi_2}{\sin\phi_2+\sin\phi_3-\sin(\phi_2+\phi_3)}$$

It is feasible to mount the three prisms with an accuracy of a degree and to make $\phi_2=\phi_3=\phi=60°$, also to give the same base angle to the three prisms, $c_1=c_2=c_3=c$, in which case $\delta R_x=2s+2c$. s is measured by means of a prism of refracting angle of about five degrees, which is mounted in front of the middle mirror (Fig. 5)

and capable of rotation round the normal facing the observer placed in the direction of A_1 (Fig. 1). The value of s gives also the height of the observer above sea-level, since the dip of the horizon is, as stated above, a function of s and c.

(*b*) In a second method the image of S is brought to a point, N, situated at equal distances, ρ, from the images of the three visible horizon lines. At this position of the index-mirror the normal to the index-prism lies at I_n and the reading is R_n. In this case

$$h = R_n - R_0 + \delta R_n,$$

where $\delta R_n = NH_1' = D + \rho$.

The perpendicular from M to $K_2'X_2$ differs from MK_2' by quantities of third order in i, c and D which are neglected.

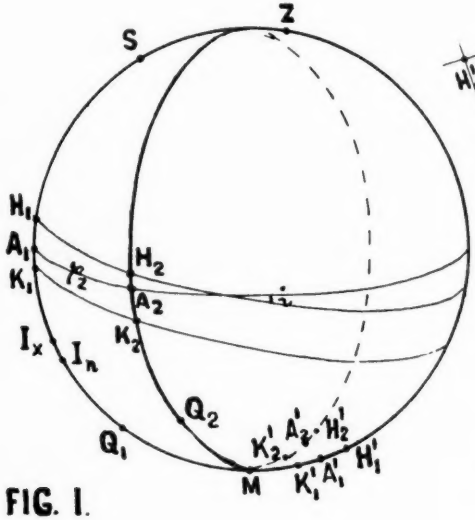


FIG. 1.

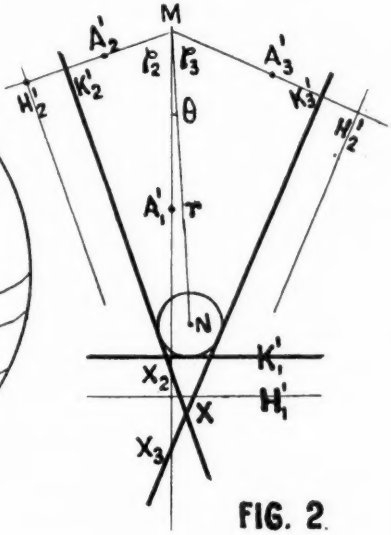


FIG. 2.

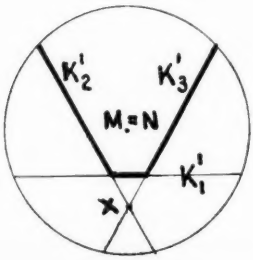


FIG. 3.

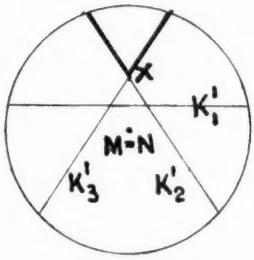


FIG. 4.

Let $MN\ (=r)$ enclose angle θ with MH_1'; then

$$\rho = MK_1' - r\cos\theta$$
$$\rho = MK_2' - r\cos(\phi_2 + \theta - i_2)$$
$$\rho = MK_3' - r\cos(\phi_3 - \theta - i_3)$$

where

$$i_2 = i\sin\phi_2, \text{ and } i_3 = i\sin\phi_3.$$

Further,

$$MK_1' = 2c_1 - D + i$$
$$MK_2' = 2c_2 - D + i\cos\phi_2$$
$$MK_3' = 2c_3 - D + i\cos\phi_3.$$

$(\rho + D)$ and $r\sin\theta$ can be eliminated from the three equations, thus giving

$$r\cos\theta = i + \frac{2(c_1 - c_2)\sin\phi_3 - 2(c_1 - c_3)\sin\phi_2}{\sin\phi_2 + \sin\phi_3 - \sin(\phi_2 + \phi_3)}$$

The second-order terms which have been omitted contain i^2 and ic. Apart from these terms, the substitution gives

$$\delta R_n = \frac{-2c_1\sin(\phi_2 + \phi_3) + 2c_2\sin\phi_3 + 2c_3\sin\phi_2}{\sin\phi_2 + \sin\phi_3 - \sin(\phi_2 + \phi_3)}$$

Here again the first power of the inclination, i, does not enter the correction to the index-error. In the case cited, where $\phi = 60°$, and the inclinations of the three mirrors are all equal to $(45° - c)$, θ becomes zero and $\delta R_n = 2c$.

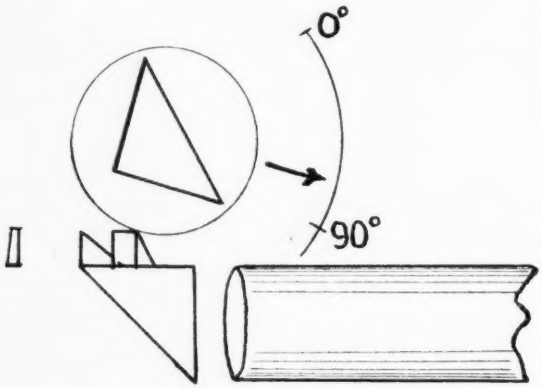


FIG. 5a

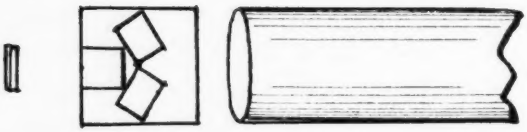


FIG. 5b

In a set of three small prisms, 8 mm. on a side, mounted on a glass plate and supplied by Messrs. Adam Hilger, Ltd., London, $c_1=0$, $c_2=+12'$, $c_3=+6'$, $\phi_2=55^\circ\ 28'$, $\phi_3=61^\circ\ 45'$, wherewith $\delta R_n=+38'$.

4. *Most Favourable Observing Condition.*—According to the above, all the second-order terms contain i. This error is the inclination at which the observer holds the instrument, and it is, therefore, important that the observer has some means of ascertaining whether he holds his instrument correctly. The error i is, for equal values of c (and the optician is aiming at that), equal to r, and hence equal to MN. But M is the centre of the field, so that i becomes small when the point N, equidistant from the images of the three visible horizons, is placed near the centre of the field. This need only be done approximately, say to $\frac{1}{2}^\circ$, since in absolute measure a degree squared is equivalent to only a minute.

Figs. 3 and 4 show the appearance in the field of view when N is placed at the centre of the field. For equal values of c, the middle horizon bisects the distance MX, and $XK_1'=s=D-2c$. The astronomical horizon, H_1', lies in the field below the visible horizon, K_1', and correspondingly for K_2' and K_3'. The light from the sky extends in the direction K to H, so that in the two cases shown in the diagrams, in which $D<2c$, and $D>2c$, the dark portion of the field is limited by the bold lines. For intense illumination of the sky the intersection, X, may be invisible for $D<2c$, and the front horizon-line may be invisible for $D>2c$. It thus appears that at daytime the second (b) mode of observing is preferable to that given under (a), provided that $D<2c$. If $c=1^\circ$, *i.e.*, the angle of inclination of the three mirrors to their base is 44°, the dip of the horizon would be smaller than $2c$ up to 5,000 metres above sea-level, and for $c=1\frac{1}{2}^\circ$ up to 10,000 metres. An inclination of about 44° appears to be the best compromise.

In most cases where both the front horizon and the intersection, X, of the other two horizons are perceptible the method (a) will be more accurate.

RESUME OF COMMERCIAL INFORMATION

SPECIAL ISSUE*

Explanatory Notes

TABLES A.1-A.7.—Operational statistics of French regular air transport companies for the years 1928-1932.

TABLE A.1.—Compagnie Internationale de Navigation Aérienne.

TABLE A.2.—Société Générale de Transport Aérien.

TABLE A.3.—Compagnie Air Orient.

TABLE A.4.—Compagnie Générale Aéropostale.

TABLE A.5.—Compagnie Air Union.

TABLE A.6.—Société pour le developpement de l'Aviation Commerciale.

TABLE A.7.—Totals—all companies.

TABLE B.—London-Paris Route: Comparison between operational statistics of the Compagnie Air Union and Imperial Airways Ltd. for the years 1928-1932.

TABLE C.—Operational statistics of Imperial Airways Ltd. for the years 1931 and 1932.

TABLE D.—Comparison between operational statistics of the French regular air transport companies and Imperial Airways Ltd. for the year 1932.

TABLE E.—Comparison between subsidy and revenue received by the French regular air transport companies and Imperial Airways Ltd. for the year 1932.

*Tables A*1-7.—These tables, which give statistics of the French regular air transport companies' operations during the years 1928-1932, have been prepared from the annual statistical tables published in the I.C.A.N. Bulletins. The statistics of individual companies are given in Tables A1-6, the figures being given first of all for each route and then in the form of totals covering the whole of the company's operations; in the case of the latter figures, the percentage increase or decrease as compared with the previous year is given. Table A7 is a summary of tables A1-6, and gives the grand totals of all companies year by year, together with the percentage increase or decrease, as compared with the previous year, in each case. With the exception of the Air Orient figures, where extension each year of the company's route has resulted in substantial increases under all headings, the statistics generally show certain definite tendencies, which can no doubt be traced largely to the general decline of trade during the past few years, *i.e.*, while the distance flown has not varied very considerably and the passenger figures show either a fairly steady increase or a slight decline followed by an increase, the mail figures, to a certain extent, and the goods figures to a greater extent, as might be expected, reflect the increasing financial and commercial stringency.

Table B.—In view of the fact that the Air Union and Imperial Airways, Ltd., have for many years operated in competition with each other over the important London-Paris route, it is thought that a comparison of the two companies' operational results over this route will be of considerable interest. Comparative statistics for the years 1928-1932 are therefore given in Table B, together with the percentage increase or decrease as compared with the previous year in each case. It will be seen that, taken as a whole, the statistics show the same

* Issued by Directorate of Civil Aviation (C.A.3).

tendencies as those referred to above under Tables A1-7. The lead held by Imperial Airways, Ltd., over the Air Union in 1928 was considerably reduced by 1931 in the case of passengers and mails, while as regards goods the Air Union had by that time gained the ascendancy. In 1932, however, Imperial Airways, Ltd., made a big step forward as regards the number of passengers carried, the increase being 98 per cent. as compared with 15 per cent. in the case of the Air Union, and thus more than regained the comparative position held in 1928, while as regards mails and goods the decrease as compared with 1931 was considerably less in the case of Imperial Airways, Ltd., than in the case of the Air Union. The improved position of Imperial Airways, Ltd., particularly so far as passenger traffic is concerned, must be largely attributed to the placing into service of the new Handley Page " Heracles " type aeroplanes.

Table C.—This table gives statistics of Imperial Airways' operations during the years 1931 and 1932 over the European and Empire routes, these figures being provided in order to assist appreciation of the statistics given in Table D. It should be noted that the substantial increase of traffic on the African service during 1932 is partly, but by no means wholly, attributable to the fact that, as mentioned in a footnote to the table, the final section, Kisumu-Cape Town, was not opened until January of that year.

Table D.—Statistics showing the total results of the operations of the French air transport companies during 1932, together with similar information concerning Imperial Airways, Ltd., are given in this table for comparative purposes, while, in addition, the percentage increase or decrease as compared with 1931 is given under each heading. It will be seen that during 1932 Imperial Airways, Ltd., carried more passengers than all the French air transport companies put together, and also improved its comparative position as regards the carriage of mails and goods. It is interesting to note that in the case of Imperial Airways, Ltd., the passenger/mile, mail ton/mile and goods ton/mile figures show considerably greater increases than the actual number of passengers and weights of mail and goods respectively, thus indicating a tendency for passengers and cargo to be carried for longer distances than formerly.

Table E.—This table enables a comparison to be made of the subsidies and revenue, both actual and in proportion to the traffic, received by the French air transport companies and by Imperial Airways, Ltd., during the year 1932.

It will be seen that, from the tax-payer's point of view, Imperial Airways, Ltd., is more economical than any one of the French companies, and that, taking the French companies as a whole, the subsidy paid per ton/mile is 15s. 6d., as compared with 5s. 6d. in the case of Imperial Airways, Ltd.

As regards the revenue per ton/mile, only one company, the Aeropostale, shows an improvement over Imperial Airways' figure, and this improvement is attributable to the fact that the former company derives a very large proportion of its revenue from the carriage of mails, which, as is well known, is the most paying form of load for air traffic.

In the case of what is perhaps the most important aspect of all, the relationship between revenue and subsidy, Imperial Airways, Ltd., holds an unchallenged position, the percentage of revenue to subsidy being 20.83 in the case of the French companies as compared with 48.33 in the case of Imperial Airways, Ltd.

FRANCE.

Operating Company	Routes	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
			kms.	miles.	kms.	miles.	Passengers (Note 1)			Mail (Note 2)			Goods (Note 3)				
							Number	Pass/kms.	Pass/miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	
COMPAGNIE INTERNATIONALE DE NAVIGATION AERIENNE	PARIS-CONSTANTINOPLE AND BRANCHES	1928	4,119	2,560	2,141,215	1,330,489	2,378	1,511,000	938,895	10,784	10.61	9,222	5,695	438,572	431.65	365,159	223,339	80
		1929	4,119	2,560	2,669,036	1,658,467	2,942	1,973,000	1,225,970	14,064	13,85	13,390	8,190	485,620	477.95	416,651	254,832	76.7
		1930	4,119	2,560	2,148,077	1,334,754	3,595	2,431,962	1,511,150	18,076	17.79	18,714	11,446	453,533	446.37	409,084	250,204	85
		1931	4,119	2,560	1,611,234	1,001,171	3,138	2,161,956	1,343,378	18,257	17.97	18,999	11,620	268,787	264.54	239,855	146,700	76
		1932	4,709	2,926	1,251,363	777,565	3,575	2,218,478	1,378,502	10,997	10.82	12,148	7,430	147,071	144.75	135,681	82,985	85.6
	PARIS-BÂLE-ZURICH	1931	492	306	75,276	46,774	608	179,720	111,672	2,767	2.72	953	583	12,406	12.21	5,296	3,239	92
		1932	492	306	87,352	54,277	496	181,264	112,633	2,058	2.03	718	439	7,988	7.86	3,170	1,939	98
	TOTALS, ALL ROUTES	1928	4,119	2,560	2,141,215	1,330,489	2,378	1,511,000	938,895	10,784	10.61	9,222	5,695	438,572	431.65	365,159	223,339	-
		1929	4,119	2,560	2,669,036	1,658,467	2,942	1,973,000	1,225,970	14,064	13.85	13,390	8,190	485,620	477.95	416,651	254,832	-
		% + or -	-	-	+ 25%		+ 24%	+ 31%		+ 30%		+ 45%		+ 11%		+ 14%		
		1930	4,119	2,560	2,148,077	1,334,754	3,595	2,431,962	1,511,150	18,076	17.79	18,714	11,446	453,533	446.37	409,084	250,204	-
		% + or -	-	-	- 20%		+ 22%	+ 23%		+ 29%		+ 40%		- 7%		- 2%		
		1931	4,611	2,865	1,686,510	1,047,945	3,746	2,341,678	1,455,946	21,024	20.69	19,952	12,203	281,192	276.76	245,151	149,939	-
		% + or -	+ 12%		- 21%		+ 4%	- 4%		+ 16%		+ 7%		- 38%		- 40%		
		1932	5,201	3,232	1,338,715	831,836	4,071	2,399,742	1,491,127	13,055	12.84	12,866	7,869	155,059	152.61	138,851	84,924	-
		% + or -	+ 13%		- 21%		+ 9%	+ 2%		- 38%		- 35%		- 45%		- 43%		

TABLE A.1.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

FRANCE (*continued*).

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance Flown		Commercial Loads										Regularity %
			kms.	miles	kms.	miles	Passengers (Note 1)			Mail (Note 2)			Goods (Note 3)				
							Number	Pass/ kms.	Pass/ Miles	kgs.	tons.	Tonne/ kms.	Ton/ Miles	kgs.	tons.	Tonne/ kms.	Ton/ Miles
SOCIETE GENERALE DE TRANSPORT AERIEN	PARIS-AMSTERDAM	1928	460	286	352,805	219,223	2,658	805,000	500,000	414	0.41	163	100	148,666	146.32	50,232	30,723	91
		1929	460	286	483,181	300,254	3,216	945,000	586,000	749	0.74	304	186	230,395	226.76	75,972	46,466	93.4
		1930	460	286	442,345	274,861	4,215	1,013,070	628,869	8,257	8.13	2,789	1,706	241,517	237.50	77,385	47,330	95
		1931	460	286	384,667	239,021	5,042	744,445	462,577	10,338	10.17	3,277	2,004	219,460	215.99	72,200	44,159	93
		1932	460	286	296,838	184,482	3,491	656,570	407,974	2,906	2.86	984	590	176,298	173.51	52,263	31,965	95.5
	PARIS-BERLIN PARIS-COLOGNE-BERLIN	1928	918	570	437,769	272,016	1,922	1,760,000	784,175	2,403	2.45	1,396	854	94,173	92.69	38,463	35,757	87
		1929	888	552	452,086	280,913	1,717	1,104,000	685,995	4,803	4.75	3,411	2,086	83,955	82.63	32,179	31,914	86.8
		1930	888	552	349,066	216,899	1,652	934,710	618,000	5,837	5.74	3,466	2,120	86,541	85.17	28,799	29,846	82
		1931	888	552	283,414	182,330	1,941	1,150,621	702,537	3,649	3.59	2,377	1,454	74,208	73.04	40,205	24,590	95
		1932	888	552	298,123	185,245	2,012	1,145,792	711,964	8,110	8.07	4,915	3,006	52,491	51.62	29,229	17,876	97
	PARIS-SARREBRUCK	1928	320	199	18,930	11,781	43	17,000	10,563	15	0.01	5	3	1,060	1.04	419	156	-
	PARIS-FRANCFORT-BERLIN	1929	985	612	126,480	78,592	843	452,000	281,000	65	0.04	347	212	11,283	11.10	5,590	3,419	95
		1930	985	612	150,265	93,364	924	454,010	282,108	16,225	15.97	8,166	4,994	26,993	26.57	15.403	9,421	90
	PARIS-SARREBRUCK-FRANCFORT-BERLIN	1931	1,010	627	137,766	85,605	1,140	467,015	290,189	12,858	12.66	4,339	2,654	23,084	28.62	14,965	9,165	97
	PARIS-SARREBRUCK-BERLIN	1932	1,010	627	156,450	97,214	1,367	567,310	352,510	12,571	12.37	8,452	5,316	22,135	21.79	11,084	6,779	97.5
	COLOGNE-MALMO	1929	670	416	52,690	30,313	200	78,000	48,470	322	0.32	145	89	3,038	2.99	1,285	786	100
		1930	670	416	56,730	35,251	197	114,144	70,926	575	0.57	257	182	2,923	2.88	2,207	1,350	87
		1931	695	432	105,375	65,477	700	278,475	173,029	1,114	1.10	513	314	9.458	9.31	4,704	2,883	96
	BRUSSELS-MALMO	1932	815	506	124,636	77,182	770	391,570	243,310	1,440	1.43	703	430	8,786	8.65	5,475	3,349	98.1
	TOTALS, ALL ROUTES	1928	1,698	1,055	809,534	503,021	4,623	2,084,000	1,294,938	2,830	2.87	1,564	957	243,899	240.05	109,114	66,736	-
		1929	3,003	1,866	1,094,427	680,080	5,976	2,677,000	1,661,276	6,529	6.45	4,307	2,973	328,669	323.48	135,228	82,585	-
		% or-	+77%		+ 35%		+ 29%	+ 24%		+121%		+106%		+35%		+24%		
		1930	3,003	1,866	998,406	620,381	6,986	2,574,943	1,599,997	30,892	30.40	14,718	9,002	357,774	352.12	145,794	87,947	-
		% or-	-		- 9%		+17%	-		+373%		+250%		+ 9%		+ 8%		
		1931	3,053	1,897	931,221	578,721	6,823	2,733,651	1,698,600	27,309	27.61	10.696	6,542	332,210	326.95	132,869	81,263	
		% or-	+ 3%		- 8%		- 3%	+ 6%		-10%		-27%		- 7%		- 7%		
		1932	3,173	1,971	876,163	544,422	6,640	2,761,042	1,715,764	26,037	25.62	12,004	7,342	259,670	255.57	98,050	59,969	-
		% or-	+ 4%		- 5%		- 3%	+ 1%		- 7%		+12%		-22%		-26%		

TABLE A.2.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads											Regularity
							Passengers (Note 1)			Mail (Note 2)				Goods (Note 3)				
			kms.	miles	kms.	miles	Number	Pass./ kms.	Pass./ Miles	kgs.	tons	Tonne/ kms.	Ton/ miles	kgs.	tons	Tonne/ kms.	Ton/ miles	%
COMPAGNIE AIR ORIENT	MARSEILLES-BEYROUTH	1928	3,226	2,024	48,078	29,874	-	-	-	-	-	-	-	-	-	-	-	-
		1929	3,256	2,024	227,469	141,343	-	-	-	337	0.33	948	560	-	-	-	-	97
		% + or-	-		+373%		-			-		-	-					
	MARSEILLES-BAGDAD) BANGKOK-SAIGON)	1930	4,850	3,013	440,827	273,918	198	235,058	146,056	3,038	2.99	8,397	5,136	3,164	3.11	8,044	3,085	98
		% + or-	+ 49%		+ 94%		-	-		+ 801%		+785%		-	-	-		
	MARSEILLES-SAIGON	1931	12,289	7,636	906,290	563,143	319	508,922	316,230	11,426	11.25	47,176	28,854	4,327	8.17	17,406	10,646	96
		% + or-	+153%		+106%		+61%	+117%		+ 276%		+462%		+163%		+245%		
	MARSEILLES-SAIGON	1932	12,289	7,636	1,221,869	759,052	598	1,367,526	849,738	11,872	11.69	31,377	55,868	8,297	8.17	32,172	19,677	97
		% + or-	-		+ 35%		+87%	+169%		+ 4%		+ 94%		-		+ 84%		

TABLE A.3.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
			kms.	miles	kms.	miles	(Passengers (Note 1)			Mail (Note 2)				Goods (Note 3)			
							Number	Pass./ kms.	Pass./ Miles	kgs.	tons.	Tonne/ kms.	Ton/ Miles	kgs.	tons.	Tonne/ kms.	Ton/ Miles	
COMPAGNIE GENERALE AEROPOSTALE	FRANCE-MOROCCO	1928	1,845	1,146	1,351,991	840,086	734	1,188,000	738,191	77,514	76.29	124,470	76,128	10,649	10.48	18,833	11,519	97
		1929	1,845	1,146	1,369,014	850,664	822	1,394,000	866,189	66,613	65.56	112,780	68,979	17,793	17.51	25,172	15,396	98
		1930	2,555	1,587	1,607,503	998,852	1,439	2,206,595	1,371,118	54,799	53.93	94,327	57,691	35,621	35.06	34,912	21,353	97
		1931	2,555	1,587	1,588,576	987,100	2,293	3,625,645	2,252,874	52,446	51.62	92,281	56,441	45,133	44.42	42,271	26,282	97
		1932	2,340	1,454	1,567,290	973,872	2,812	4,248,974	2,640,193	50,570	49.77	89,064	54,475	48,452	47.69	44,660	27,315	91.8
	MARSEILLES-PERPIGNAN MARSEILLES-BARCELONA	1928	275	170	171,373	106,486	187	54,000	33,550	12,999	12.79	3,576	2,187	1,578	1.55	436	267	96
		1929	495	307	238,133	147,968	166	53,000	32,930	13,835	13.62	4,602	2,815	3,020	3.56	1,247	763	86.4
	FRANCE-S.AMERICA	1928	12,785	7,944	1,313,052	815,890	150	403,000	250,000	17,853	17.40	90,044	55,073	4,765	4.69	13,588	7,699	95
		1929	13,985	8,690	1,433,329	890,630	37	120,000	74,560	28,421	27.97	168,284	103,928	3,599	3.54	13,591	8,312	97
	(see note 4)	1930	13,985	8,690	1,393,572	865,923	180	261,165	162,243	33,896	33.36	206,465	126,278	5,785	3.72	11,732	7,176	95
		1931	13,855	8,609	1,079,590	670,825	256	377,510	234,574	31,066	30.57	200,155	122,419	6,325	6.22	13,988	8,555	98
		1932	13,855	8,609	1,101,295	684,315	249	392,545	243,910	30,842	30.45	208,833	127,727	5,752	5.66	13,033	7,971	99.3
	TOULOUSE-BORDEAUX	1928	215	133	18,490	11,489	-	-	-	2,284	2.25	468	286	10	0.01	2	1	99
		1929	215	133	23,005	14,295	4	1,000	620	1,200	1.15	257	147	495	0.49	138	84	89.8
	MARSEILLES-ALGIERS	1928	803	499	70,664	43,909	-	-	-	297	0.29	240	147	753	0.74	605	370	67
		1929	803	499	276,935	172,079	4	1,000	620	2,487	2.45	1,997	1,221	3,666	3.61	2,943	1,800	86.5
		1930	803	499	440,231	273,547	5	4,015	2,495	10,048	9.89	8,068	4,935	5,880	5.79	4,721	2,887	84
		1931	803	499	453,654	281,887	59	31,317	19,458	12,839	12.64	10,310	6,306	5,705	5.61	4,579	2,801	86
		1932	803	499	476,479	296,071	111	87,527	54,386	13,527	13.31	10,859	6,642	5,717	5.63	4,593	2,809	89.9
	PARIS-BIARRITZ (TRIAL)	1928	680	422	35,930	22,326	54	34,000	21,130	129	0.13	75	49	63	0.06	46	28	-
	" -MADRID	1929	1,200	746	168,995	105,008	275	191,000	118,700	782	0.77	481	294	1,266	1.25	912	558	97
	" "	1930	1,200	746	113,780	70,700	493	317,255	197,133	422	0.42	269	165	5,677	5.59	4,017	2,457	98

TABLE A.4.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
							Passengers (Note 1)			Mail (Note 2)			Goods (Note 3)				
			kms.	miles	kms.	miles	Number	Pass./ kms.	Pass./ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	kgs.	tons.	Tonne/ kms.	Ton/ Miles	
COMPAGNIE GENERALE AEROPOSTALE (continued)	TOTALS ALL ROUTES	1928	16,603	10,317	2,961,500	1,840,195	1,125	1,679,000	1,043,300	110,906	109.15	218,873	135,867	17,818	17.54	32,460	19,853	-
		1929	18,543	11,523	3,509,410	2,180,647	1,308	1,760,000	1,093,580	113,338	111.51	288,401	176,392	30,439	29.96	44,003	26,919	-
		% + or -	+ 12%		+ 19%		+ 16%	+ 5%		+ 2%		+ 32%		+ 71%		+ 36%		
		1930	18,543	11,523	3,555,086	2,209,028	2,117	2,788,970	1,732,984	99,165	97.60	309,129	189,070	50,953	50.15	56,182	34,362	-
		% + or -	-		+ 1%		+ 54%	+ 58%		- 12%		+ 7%		+ 67%		+ 28%		
		1931	17,213	10,695	3,121,822	1,939,810	2,588	4,034,472	2,506,910	96,341	94.81	302,746	185,166	57,163	56.26	61,538	37,638	-
		% + or -	- 7%		See Note 4		+ 22%	+ 45%		- 3%		- 2%		+ 12%		+ 10%		
		1932	16,998	10,562	3,145,064	1,954,252	3,172	4,729,046	2,938,498	95,039	93.54	308,756	188,842	59,921	58.97	62,286	38,095	-
		% + or -	- 1%		+ 1%		+ 23%	+ 17%		- 1%		+ 2%		+ 5%		+ 1%		

TABLE A.4 (*continued*).

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.
(4) Figures under column headed "Distance flown" for the years 1928, 1929 and 1930 include steamer mileage, whereas those for the years 1931 and 1932 only comprise distance flown by aircraft.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
								Passengers (Note 1)			Mail (Note 2)			Goods (Note 3)			
			kms.	miles	kms.	miles	Number	Pass./ kms.	Pass./ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	
COMPAGNIE AIR UNION	PARIS-LONDON	1928	375	233	700,629	435,351	8,541	3,204,000	1,990,875	1,985	1.95	745	456	425,033	418.32	160,391	98,096	87
		1929	375	233	950,606	590,679	10,649	3,993,000	2,481,138	3,599	3.54	1,331	814	691,304	680.39	259,228	158,549	75
		1930	375	233	914,540	568,269	9,705	3,638,875	2,261,096	5,946	5.85	2,269	1,388	635,503	625.47	235,760	144,196	90
		1931	375	233	1,026,256	637,685	12,763	4,786,135	2,973,972	11,215	11.04	4,207	2,573	828,191	815.11	291,895	178,529	95
		1932	375	233	960,397	596,764	14,633	5,487,575	3,409,702	8,679	8.54	3,255	1,991	581,779	572.52	218,165	133,434	97.1
	PARIS-MARSEILLES	1928	730	454	406,304	252,466	1,462	896,000	556,749	1,801	1.77	1,065	651	25,933	25.52	14,043	8,589	80
		1929	730	454	531,325	330,150	2,500	1,460,000	907,202	2,700	2.66	1,597	978	45,434	44.72	27,089	16,568	89.7
		1930	730	454	579,745	360,237	2,936	1,720,385	1,069,307	5,055	4.98	2,714	1,660	72,593	71.45	43,476	26,591	95
		1931	730	454	556,990	346,097	2,998	1,788,965	1,111,610	6,907	6.80	3,516	2,150	81,196	79.91	49,181	30,080	97
		1932	730	454	616,755	383,234	4,539	2,436,440	1,513,933	6,309	6.21	3,308	2,023	83,540	82.22	46,070	28,177	97.6
	MARSEILLES-TUNIS	1928	1,103	685	193,132	120,007	1,910	525,000	326,220	891	0.88	684	418	1,705	1.68	936	572	95
	" -BONE	1929	1,295	804	301,962	187,631	879	583,000	362,280	2,411	2.37	2,202	1,347	3,773	3.71	3,128	1,913	82.6
		1930	1,293	804	567,604	352,693	1,961	1,358,136	843,904	17,091	16.82	16,492	10,087	9,446	9.30	8,058	4,928	83
		1931	1,293	804	630,091	391,520	3,147	2,225,102	1,382,618	11,662	11.48	10,482	6,411	13,194	12.99	10,409	6,366	92
		1932	1,293	804	672,624	417,950	3,239	2,381,649	1,479,884	11,977	11.79	10,436	6,383	14,029	13.81	9,594	5,868	95.9
	LYONS-GENEVA	1928	113	70	36,612	22,749	559	61,000	37,904	1,088	1.07	123	75	3,459	3.40	391	239	97
		1929	113	70	55,008	34,180	905	102,000	63,360	1,018	1.00	112	69	4,815	4.74	543	332	92.2
		1930	113	70	67,410	41,887	1,228	136,052	85,781	3,020	2.97	342	209	11,342	11.16	1,280	783	-
	PARIS-LYONS-GENEVA	1931	558	347	73,028	45,421	316	116,968	72,681	377	0.37	185	113	4,097	4.03	1,828	1,118	98
	PARIS-GENEVA AND LYONS-GENEVA	1932	533	331	120,892	75,119	2,069	342,168	212,613	4,014	3.95	515	315	24,550	24.16	3,492	2,136	-
	LYONS - CANNES	1932	350	217	185,590	115,320	1,530	535,500	332,745	187	0.18	65	40	15,870	15.62	5,550	3,394	-

TABLE A.5.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
							Passengers (Note 1)			Mail (Note 2)			(Goods (Note 3)				
			kms.	miles	kms.	miles	Number	Pass./ kms.	Pass./ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	kgs.	tons	Tonne/ kms.	Ton Miles	
COMPAGNIE AIR UNION (continued)	TOTALS ALL ROUTES	1928	2,321	1,442	1,336,677	830,569	11,572	4,686,000	2,911,748	5,765	5.67	2,617	1,600	456,128	448.93	175,761	107,499	-
		1929	2,511	1,560	1,838,901	1,142,642	14,933	6,138,000	3,813,982	9,728	9.57	5,242	3,206	745,326	733.55	289,988	177,363	-
		% + or -	+ 8%		+ 38%		+ 29%	+ 31%		+ 69%		+100%		+ 63%		+ 65%		
		1930	2,511	1,560	2,129,299	1,323,086	15,830	6,855,946	4,260,094	31,112	30.62	21,817	13,344	728,884	717.37	288,574	176,428	-
		% + or -			+ 16%		+ 6%	+ 12%		+220%		+316%		- 2%				
		1931	2,956	1,837	2,286,435	1,420,728	19,224	8,917,170	5,540,879	29,861	28.39	18,390	11,248	926,678	912.06	353,313	216,094	-
		% + or -	+ 18%		+ 7%		+21%	+ 30%		- 4%		- 16%		+ 27		+ 22%		
		1932	3,281	2,038	2,556,258	1,588,367	26,010	11,183,132	6,948,893	31,166	30.67	17,579	10,752	719,768	708.40	282,871	173,010	-
		% + or -	+ 11%		+ 12%		+35%	+ 25%		+ 4%		- 4%		-22%		- 20%		

TABLE A.5 (*continued*).

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

FRANCE (*continued*).

Operating Company	Route	Year	Length of Route		Distance flown		Commercial Loads										Regularity %
							Passengers (Note 1)			Mail (Note 2)				Goods (Note 3)			
			kms.	miles	kms.	miles	Number	Pass./ kms.	Pass./ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	kgs.	tons	Tonne/ kms.	Ton/ Miles	
SOCIETE POUR LE DEVELOPPEMENT DE L'AVIATION COMMERCIALE	MONTLUCON–GENEVA (operated for one year only)	1929	323	200	95,181	59,764	101	14,000	8,700	5,402	5.32	1,099	672	13,542	13.33	2,650	1,621	95 ·

TABLE A.6.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

FRANCE (*continued*).

Year	Total Length of Routes		Distance flown		Commercial Loads										
	Kms	Miles	Kms.	Miles	Passengers (Note 1)			Mail (Note 2)				Goods (Note 3)			
					Number	Pass/kms.	Pass/Miles	kgs.	Tons	Tonne/kms	Ton/Miles	kgs	Tons	Tonne/kms	Ton/Miles
1928	27,997	17,398	7,297,004	4,534,148	19,698	9,960,000	6,188,878	130,375	128.30	232,276	142,119	1,156,417	1,138.17	682,494	417,427
1929	31,755	19,733	9,435,434	5,862,913	25,260	12,462,000	7,743,508	149,398	147.01	313,287	191,613	1,603,596	1,578.27	888,318	543,320
%+or-	+ 13%		+ 29%		+ 28%	+ 25%		+ 15%		+ 35%		+ 39%		+ 30%	
1930	33,028	20,522	9,271,695	5,761,167	28,726	14,886,881	9,250,283	182,283	179.40	372,775	227,998	1,594,308	1,569.12	902,678	552,096
%+or-	+ 4%		- 2%		+ 14%	+ 19%		+ 22%		+ 19%		- 1%		+ 2%	
1931	40,122	24,927	8,922,278	5,544,047	32,700	18,535,892	11,517,674	186,611	183.65	398,960	244,013	1,605,570	1,580.20	810,273	495,580
%+or-	+ 21%		- 4%		+ 14%	+ 25%		+ 2%		+ 7%		+ 1%		- 10%	
1932	40,942	25,439	9,137,769	5,677,950	40,491	22,440,688	13,944,011	177,169	174.37	442,582	270,693	1,202,715	1,183.72	614,230	375,675
%+or-	+ 2%		+ 2%		+ 24%	+ 21%		- 5%		+ 11%		- 25%		- 24%	

TABLE A.7.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

LONDON-PARIS ROUTE

LONDON–PARIS ROUTE.

Comparison between Operational Results of Air Union and Imperial Airways Ltd. for the Years 1928–1932.

Year	Company Operating	Distance flown		Commercial Loads										
				Passengers (Note 1)			Mails (Note 2)				Goods (Note 3)			
		Kms.	Miles	Number carried	Pass./Kms.	Pass./Miles	Kg.	Tons	Tonnes/Kms.	Ton/Miles	Kg.	Tons	Tonnes/Kms.	Ton/Miles
1928	Air Union.	700,629	435,351	8,541	3,204,000	1,990,875	1,985	1.95	745	456	425,033	418.32	160,391	98,098
	Imperial Airways	825,332	512,838	20,434	7,662,276	4,761,122	16,125	15.87	6,046	3,698	539,094	530.58	202,127	123,625
1929	Air Union	950,606	590,679	10,649	3,993,000	2,481,138	3,599	3.54	1,331	814	691,304	680.39	259,228	158,549
	Imperial Airways	790,326	491,086	20,935	7,850,135	4,877,855	21,144	20.81	7,928	4,849	627,352	617.64	235,293	143,910
%Increase or decrease over previous year	Air Union	+36%			+25%				+80%				+62%	
	Imperial Airways	-4%			+ 2%				+31%				+16%	
1930	Air Union	914,540	568,269	9,705	3,638,875	2,261,095	5,946	5.85	2,269	1,388	635,503	625.47	238,760	144,196
	Imperial Airways	733,134	445,449	17,512	6,566,594	4,080,296	22,851	22.49	8,567	5,240	645,729	487.65	186,782	113,622
%Increase or decrease over previous year	Air Union	-4%			-9%				+68%				-8%	
	Imperial Airways	-9%			-16%				+8%				-21%	
1931	Air Union	1,026,256	637,685	12,763	4,786,135	2,973,972	11,215	11.04	4,207	2,573	828,191	815.11	291,895	178,589
	Imperial Airways	698,615	434,100	18,302	6,862,827	4,264,366	26,305	25.89	9,852	6,032	496,380	488.54	186,112	113,830
%Increase or decrease over previous year	Air Union	+12%			+31%				+86%				+27%	
	Imperial Airways	-3%			+5%				+15%				-	
1932	Air Union	960,397	596,764	14,633	5,487,375	3,409,702	8,679	8.54	3,255	1,991	581,779	572.59	218,165	133,424
	Imperial Airways	729,121	453,055	36,308	13,614,561	8,459,764	24,731	24.34	9,272	5,671	384,005	377.94	143,978	88,060
%Increase or decrease over previous year	Air Union	-6%			+15%				-27%				-27%	
	Imperial Airways	+4%			+98%				-6%				-23%	

TABLE B.

NOTES.

(1) Does not include personnel of the Companies.
(2) Includes parcels.
(3) Comprises paying goods, paying baggage and newspapers.

Operational Statistics of Imperial Airways Ltd. for the Years 1931 and 1932.

YEAR	MILES FLOWN	HORSE-POWER/ MILES	PASSENGERS CARRIED (BY STAGES	PASSENGER/ MILES	CARGO TON/MILES		PASSENGER TON/MILES	TOTAL TON/MILES	AVERAGE LOAD (LBS.)
					FREIG	MAILS			
EUROPEAN SERVICES (EXCLUDING LONDON-EGYPT).									
1931	623,000	797,339,000	23,834	4,918,000	139,100	14,800	439,200	593,100	2,130
% increase or decrease over previous year.	(-8%)	(-0·7%)	(-1%)	(-4%)	(-11%)	(-19%)	(-4%)	(-6%)	(-3%)
1932	656,700	1,135,299,000	44,883	9,611,000	128,300	12,400	858,100	998,800	3,410
% increase or decrease over previous year.	(+5%)	(+42%)	(+88%)	(+95%)	(-8%)	(-16%)	(+95%)	(+68%)	(+60%)
LONDON-EGYPT SERVICE									
1931	170,800	319,228,000	2,770	857,000	29,100	81,900	84,500	195,500	2,560
% increase or decrease over previous year.	(+2%)	(+45%)	(+71%)	(+115%)	(+44%)	(+21%)	(+115%)	(+54%)	(+51%)
1932	224,400	496,261,000	6,401	2,136,000	52,200	90,700	210,700	553,600	3,530
% increase or decrease over previous year.	(+31%)	(+55%)	(+131%)	(+149%)	(+79%)	(+11%)	(+149%)	(+81%)	(+38%)
EGYPT-INDIA SERVICE									
1931	259,300	335,859,000	1,890	529,000	21,500	102,400	52,200	176,100	1,520
% increase or decrease over previous year	-	(+1%)	(+15%)	(+5%)	(+15%)	(+9%)	(+3%)	(+8%)	(+8%)
1932	267,400	517,471,000	4,586	1,267,000	24,900	99,200	125,000	249,100	2,090
% increase or decrease over previous year.	(+3%)	(+54%)	(+143%)	(+140%)	(+16%)	(+3%)	(+139%)	(+41%)	(+38%)
EGYPT-SOUTH AFRICA SERVICE									
1931	223,900	304,495,000	2,883	705,000	10,800	15,800	69,500	96,100	960
1932	585,200	772,165,000	11,683	2,940,000	47,300	74,900	290,100	412,500	1,580
% increase or decrease over previous year.	(+162%)	(+154%)	(+305%)	(+317%)	(+538%)	(+374%)	(+317%)	(+329%)	(+65%)

NOTE:- The service Cairo-Kisumu commenced 6.5.1931 and was extended from Kisumu to Cape Town thereby completing the Cairo-Cape Town route, on 25.1.1932.

TABLE C.

Comparison between Operational Statistics of the French Regular Air Transport Companies and Imperial Airways Ltd. for the Year 1932.

LENGTH OF ROUTE		DISTANCE FLOWN		COMMERCIAL LOAD										
					PASSENGERS		MAIL				GOODS			
KMS.	MILES	KM.	MILES	NUMBER	PASS./KM.	PASS./MILES	KG.	TONS	TONNE/KMS.	TON/MILES	KG.	TONS	TONNE/KMS.	TON/MILES
FRANCE														
40,942 (+2%)	25,439	9,137,769 (+2%)	5,677,950	40,491 (+24%)	22,440,688 (+21%)	13,944,011	177,169 (-5%)	174.37	442,582 (+11%)	270,693	1,202,715 (-25%)	1,183.72	614,230 (-24%)	375,675
UNITED KINGDOM		(IMPERIAL AIRWAYS LTD.)												
18,126 (+45%)	11,263	2,842,697 (+30%)	1,766,000	45,150 (-9%)	25,675,419 (+123%)	15,954,000	141,330 (+16%)	139.00	453,222 (+2%)	277,200	640,110 (-3%)	630.00	413,164 (+26%)	252,700

TABLE D.

NOTE.

Figures in brackets denote the percentage increase or decrease of 1932 results over 1931 results.

Comparison between Subsidy and Revenue Received by the French Regular Air Transport Companies and Imperial Airways Ltd. for the Year 1932.

COMPANY	TON/MILES	SUBSIDY RECEIVED		SUBSIDY PER TON/MILE		REVENUE		REVENUE PER TON/MILE		TOTAL INCOME (SUBSIDY + REVENUE)		INCOME PER TON/MILE		% REVENUE SUBSIDY
		Frs.	£.	Frs.	£. s. d.	Frs.	£.	Frs.	£. s. d.	Frs.	£.	Frs.	£. s. d.	
AIR UNION	878,651	32,500,000	261,653	37·0	6. 0	12,811,000	103,142	14·6	2. 4	45,311,000	364,795	51·6	8. 4	28·26%
FARMAN	238,886	13,500,000	108,687	56·5	9. 1	3,660,000	29,466	15·3	2. 6	17,160,000	138,153	71·8	11. 7	21·33%
C.I.D.N.A.	241,906	21,000,000	169,068	86·8	14. 0	3,839,000	30,908	15·9	2. 7	24,839,000	199,976	102·7	16. 7	15·46%
AIR ORIENT	160,539	49,560,000	399,002	308·7	2. 9. 9	3,389,000	27,285	21·1	3. 5	52,949,000	426,287	329·8	2.13. 1	6·40%
AEROPOSTALE	520,787	80,000,000	644,070	153·6	1. 4. 9	28,021,000	225,594	53·8	8. 8	108,021,000	869,664	207·6	1.13. 5	25·94%
TOTAL	2,040,769	196,560,000	1,582,480	96·3	15. 6	51,720,000	416,395	25·3	4. 1	248,280,000	1,998,875	121·6	19. 7	20·83%
IMPERIAL AIRWAYS LTD.	1,987,223	68,309,290	549,950	34·0	5. 6	63,904,927	514,491	32·0	5. 2	132,214,217	1,064,441	66·0	10. 8	48·33%

TABLE E.

NOTES.

(1) Par rate of exchange: £1 = 124.21 francs.
(2) In the above calculations 10 passengers have been assumed to equal 1 ton of load.

PRINCIPLES OF ROCKET PROPULSION

BY

HERBERT CHATLEY, M.INST.C.E., A.F.R.AE.S., D.SC. ENGRG.

Preliminary

A great deal of interest has recently been taken in the subject of rocket propulsion, undoubtedly in the main due to the rather extravagant hopes, raised by Professor Goddard (1) in 1919, that a projectile might actually be sent into interplanetary space. Esnault-Pelterie (2) and Hermann Oberth (3) have more recently reaffirmed this possibility. Experiments by the late Max Valier, Reinhold Tilling, Darwin Lyon, Goddard himself and others have sustained the attention given to the matter. Prof. Richardson's article on jet propulsion (AERONAUTICAL JOURNAL, Jan., 1931) should be referred to. Mr. David Lasser's recent book (4) gives a fair general view of the subject, and the author's paper to the Society of Engineers (May 2nd, 1932) may also be of interest.

No useful purpose would be served here by going into great mathematical detail as to extra-terrestrial flight. This has already been done in several of the works referred to (Pelterie even discusses relativity corrections for voyages to the nearer stars!) and in this paper attention has been confined to the main practical questions, from a solution of which the development of long range rockets *may* perhaps ultimately appear.

Fundamental Theory of Vertical Rocket Flight

The rocket depends for its action on recoil; the lifting force applied to a rocket is the vertical component of the momentum per second carried away by the discharged gases. Assuming the rocket to have the form of a solid of revolution and that its axis is vertical and that the equivalent axial velocity of the ejected gases is c, the condition of sustentation is

$$mc \geq W \qquad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where m is the mass of gas ejected per second.

W is the momentary weight of the rocket.

If $mc > W$ a surplus force is available to overcome air resistance and to produce acceleration.

In the initial state when velocity is zero, or at any velocity in the vacuum, the differential equation of motion is

$$mc = W + (W/g)\,(dv/dt) \qquad . \quad . \quad . \quad . \quad (2)$$

After a velocity has developed, if the air resistance varies as the square of the velocity (vide infra)

$$mc = W + CAv^2 + (W/g)\,(dv/dt) \qquad . \quad . \quad . \quad . \quad (3)$$

where A is the effective sectional area, v the velocity and C a drag coefficient.

Since the momentary weight diminishes by the progressive ejection of the propellent in the form of gas

$$W = W_0 - \int_0^t mg \,.\, dt$$

where W_0 is the initial weight and t is the time since the combustion started. If m is constant

$$W = W_0 - mgt$$

In the most simple case the general equation of motion is therefore as follows:—

$$mc=(W_o-mgt)+CAv^2+\{(W_o-mgt)/g\}(dv/dt) \quad . \quad . \quad (4)$$

This equation can be manipulated in various ways, although it obviously does not lend itself to a simple integration.

Thus $mc \geqq W_o$ and when the velocity is a maximum

$$mc=(W_o-mgt_1)+CAv^2 \quad . \quad . \quad . \quad . \quad (4a)$$

where t_1 is the time of reaching maximum velocity v_1.

NOTE.—Obviously t_1 is normally equal to t_2 in equation (5) below and then

$$mc=W_2+CAv_1^2 \quad . \quad . \quad . \quad . \quad . \quad (4b)$$

If the final (empty) weight of the rocket is W_2 and t_2 is the whole period of combustion

$$mt_2=(W_o-W_2)/g \quad . \quad . \quad . \quad . \quad . \quad (5)$$

If $W_2=kW_o$ and $mc=qW_o$ $[q \geqq 1]$ we have

$$q(W_o/c)t_2=W_o(1-k)/g$$

$$t_2=c(1-k)/qg \quad . \quad . \quad . \quad . \quad . \quad (6)$$

In the limit

$$t_2 < c/g \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

or, is there an accelerating force $(W/g)\,a$, $t_2 < c/(g+a)$.

Oberth and Pelterie (vide infra) indicate a possible value for $c=4{,}000$ metres/second and taking g as 10 m./sec.^{2} this makes t_2 for constant rate of combustion $=400$ seconds. (If the rate of combustion diminishes this time can be prolonged, but of course at the expense of the surplus thrust; 600 *seconds appears to be about the extreme practical limit for the duration of combustion.*)

NOTE.—In the case of motion in a vacuum one comparatively simple and interesting case should be mentioned.

If we write $m=dW/g\,dt$

$$dW/g\,dt\,.\,c=W+(W/g)(dv/dt)$$

and consider the case when dv/dt is constant $=a$

$$dW/dt=(W/c)(g+a)$$

and

$$W=W_o\epsilon^{-(g+a)\,t/c}$$

which means that constant acceleration a will occur in a vacuum if the total weight diminishes exponentially, and, when $t=c/(g+a)$, this weight has been reduced from W_o to W_o/ϵ. This case involves a reduction of the rate of combustion so as to bear a constant ratio to the momentary weight of the rocket.

Value of the Maximum Velocity with Constant Thrust

The equation (4*b*) gives a value of the maximum velocity

$$v_1=\{(mc-W_2)/CA\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (8)$$

and inserting the values used in (6) $[mc=qW_o,\ W_2=kW_o]$

$$v_1=\{W_o(q-k)/CA\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (8a)$$

If for W_o we write $sg\,.\,zAl$

where s is the mean density of the filled rocket,

z is the block coefficient,

l is the length of the rocket,

we have

$$v_1=\{sgzl(q-k)/C\}^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad (9)$$

which shows that the maximum velocity varies as

the square root of the density,

" " fineness coefficient,*

" " length,*

" " difference between the thrust and the final weight,

" " reciprocal of the resistance coefficient.

If, for example, $C=0.0004\ \rho/\rho_0$ dynes per cm.^{2} at 1 cm./sec.; $q=2$; $k=0.25$; $z=\frac{1}{2}$; $s=1.5$; $\rho=$air density at position and ρ_0 air density at ground.

$$v_1=\sqrt{\{(1.5\times 981\times\tfrac{1}{2}\times l\times 1.75)/(0.0004\ \rho/\rho_0)\}}$$
$$=\sqrt{\{(1.3\times 10^7\times l)/(4\ \rho/\rho_0)\}}$$
$$=10^3\sqrt{(3.25\ l\ \rho_0/\rho)}$$

say $l=10$ metres $=1{,}000$ cms. and say $\rho_0/\rho=2$.

$$v_1=10^4\sqrt{65}\text{ cms./sec., say 800 metres/second.}$$

If the coefficient of resistance can be halved by good formation this velocity will be increased in the ratio $\sqrt{2}$, *i.e.*, to 1,200 metres per second. With a velocity of the order of hundreds of metres per second, in the course of a few seconds the increase of height will reduce the air density to say $\frac{1}{4}$, which increases the final velocity again in the ratio $\sqrt{2}$, making it about 1,600 metres/second.

If q is increased the value of v_1 may be appreciably enlarged, but in this case the velocity and corresponding resistance is developed earlier so that the duration of propulsion and the consequent range are diminished. Thus, if $(q-k)=3.50$, v_1 is doubled but the duration is about halved.

For the purpose of rough computation the mean velocity may be given as $2/3\ v_1$ so that if the duration of the propulsion (equation 6) is combined with that for the final velocity (No. 9) we have the vertical range up to the end of the propulsion as

$$h=(2/3)\sqrt{\{sgzl\,(q-k)/C\}}\ c\,(1-k)/qg \quad . \quad . \quad . \quad (10)$$

Thus, in the example given above, if $c=2{,}000$ m./sec.; $k=0.25$; $q=2$; $g=$say 10 m./sec.^{2}

$$h=2/3\times 800\times(2{,}000\times 0.75)/(2\times 10)=40{,}000\text{ metres}=40\text{ kilometres.}$$

At 40 kilometres the density of the air is quite small and the inertial range due to the final velocity will tend towards the value

$$v_1^2/2g=800^2/20=32{,}000\text{ metres}=32\text{ kilometres}$$

making a total of not much less than 70 kilometres.

Propellent

The feature which is at once both the virtue and the defect of the rocket is that it is independent of outside sources for its operation. The propellent must contain all the ingredients of combustion and two classes of material occur:—

(*a*) Explosive mixtures or compounds of the usual solid or liquid types.
(*b*) Liquid fuels with adequate supply of oxygen, also in a liquid form.

The ordinary type of rocket and the earlier experimental types of long range rocket have solid explosives and the heat of combustion is of the order of 1,000 calories per gram. If this heat could be *wholly* converted into kinetic energy we should have

$$1{,}000\times 4.2\times 10^7\text{ ergs}=c^2/2$$
$$\text{so that } c^2=8.4\times 10^{10}$$
$$\text{and } c=2.8\times 10^5=2{,}800\text{ metres per second.}$$

In actual rockets of the usual signalling type the gas discharge velocity is only about 400 metres per second, corresponding to an efficiency of $(400/2{,}800)^2$ = about 2 per cent.

Goddard has shown that with diverging nozzles of small taper the thermodynamic efficiency can be increased to some 70 per cent., and he actually obtained with ordinary explosives discharge velocities up to 2,400 metres per second.

Oberth and Pelterie have shown that with hydrogen and oxygen in optimum ratio (allowing for dissociation) about 3,000 calories per gram are obtainable, indicating possible nozzle velocities of 4,000 metres per second.

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* These two are opposed in sense so that an equivalent length can be used.

A practical difficulty is that the energy is first developed in the form of intense heat and pressure which has to be converted gradually into kinetic energy. This necessitates a very strong combustion chamber to which the propellent must be gradually fed. Goddard has a number of patents for the mechanical feeding of cartridges (U.S. patents 1,103,503, 1,191,299, 1,194,496, 1,206,837, 1,311,885, 1,341,053, 1914-1920), but most recent experiments are with liquids, involving peculiar difficulties of temperature and pressure. Liquid oxygen has its critical temperature so low that evaporation under practical conditions is very rapid and the method adopted is to place this material (and also the other constituent if its normal state is gaseous) into the reservoirs at the last moment and use the vapour pressure to drive it to the nozzles in the combustion chamber.

Dynamics of Ordinary Rocket

If a rocket weighing 1,000 grams contains a charge of 200 grams of explosive, giving an effective ejection velocity of 400 metres per second, the following general conditions will approximately obtain.

The initial thrust must exceed 1,000 grams and may be taken at 2,000 grams (2 kilos) so that (k.m.s. system)

$$m\ (400) = 2$$

$$m = 1/200 = w/g;\ w = g/200 = 1/20 \text{ kilog. per sec.}$$

or 50 grams per second. The charge will therefore burn for 4 secs.

At the end of this time the rocket only weighs 800 grams and the acceleration (disregarding air resistance) will be

$$a = (2.0 - 0.8)/0.8\ .\ g = 15 \text{ metres/sec.}^2$$

as compared with the initial acceleration upwards of about 10 metres per second. If this *increase* (5 m./sec.^{2}) of acceleration is actually annulled by the air resistance the actual distance travelled in the four seconds of combustion is 80 metres and the maximum velocity will be 40 metres per second. In a vacuum this would cause a further rise of 80 metres, but the air resistance will reduce this to about 40 metres making an appropriate total ascent of 120 metres. When it is considered that the 200 grams of explosive contained, at 1,000 cals. per gram,

$$200 \times 1{,}000 \times 4.2 \times 10^7 \text{ ergs}$$

and that this was applied to a net weight of 800 grams (800×981 dynes), which might have been lifted, under ideal conditions, to

$$(200 \times 1{,}000 \times 4.2 \times 10^7)/(800 \times 981) = \text{say } 10^7 \text{ cms.} = 100{,}000 \text{ metres,}$$

it is clear how extraordinarily inefficient the ordinary rocket is and what scope there is for improvement. One reason for the bad result, as already indicated, is the poor thermodynamic efficiency of the nozzle. Most of the energy is wasted in the lateral expansion of the gases after they leave the rocket. This is largely remediable by the use of a long divergingly tapered nozzle, but there is another less curable defect, *i.e.*, the loss of kinetic energy in the discharged gases. This can only be cured by the development of very high velocities of travel.

Energy Loss in Discharged Stream

Even if the thermodynamic operation of the nozzle is good there still remains to be considered the mechanical action. If the velocity of the rocket in space is v and the thrust is mc the work done per second is mcv, but the ejected gases have a velocity in space ($c \sim v$) so that there is a wasted kinetic energy $(c \sim v)^2/2$ per unit mass of ejected gas. Hence the mechanical energy used per second is

$$mcv + m\ (c - v)^2/2$$

and the ratio of the useful energy to the total is

$$cv/\ \{\ cv + (c - v)^2/2\ \} = 2cv/(c^2 + v^2)$$

which is very small for small values of c/v or v/c and unity when $c = v$.

(This is entirely different from propeller action, which is most efficient for small relative motion.)

An interesting point is that in this case the thrust work is $cv = c^2 = v^2 = 2c^2/2$, *i.e.*, twice the kinetic energy of ejection, the difference being made up by the kinetic energy of forward motion which the ejected material previously had in the rocket.

Since the maximum thrust occurs with maximum velocity of ejection (say 4,000 metres per second) and maximum mechanical efficiency occurs when the forward velocity of the rocket has this same value, we see that *a rocket has its highest efficiency at this enormous speed* (4 kilometres per second or say $2\frac{1}{2}$ miles per second). Using ordinary explosives which cannot produce much more than 2,000 metres per second ejection velocity, that same velocity is the most suitable one for the travel of rockets with such explosives.

At the " parabolic " vertical speed required to overcome continuously the earth's gravitational attraction (11 kilometres per second) the mechanical efficiency is still

$$(4 \times 11)/(4^2 + 11^2) = \text{about } \tfrac{1}{3}$$

which is better than occurs at " low " speeds, say 1 kilometre per second, which gives

$$(4 \times 1)/(4^2 + 1) = 5/17$$

or 1/10 kilometre per second, which gives about 1/40.

Relative Efficiency of Rocket and Screw Propulsion in Air

The efficiency of rocket propulsion is much inferior to that of the gas engine screw propeller system at ordinary speeds in air, on two accounts:—

(*a*) The fuel load is more since the rocket carries both the constituents of combustion, while the gas engine only carries one. Thus, in an ideal case of carbon burning in oxygen the ratio of the mass of the whole constituents to that of the " fuel " is $(12+32)/12 = 3.7$.

For hydrogen-oxygen the ratio is $(2+16)/=9$.

For gasoline-oxygen the ratio is about 4.5. For a gasoline-air mixture the ratio would be about 20, but this case does not occur since it would be irrational to carry (liquid) air in a rocket when oxygen could be used.

(*b*) The loss of kinetic energy in the stream of ejected fluid is much greater in the rocket jet, even in spite of a potentially superior thermodynamic conversion of the calorific energy.

If we consider the case of a propeller in which the consumption of gasoline per thrust horse-power hour is three-quarters pound, if the calorific value of the fuel is 7,000 calories per gram, the overall efficiency is about one-quarter. In the case of a rocket using a mixture with a calorific value of 3,000 calories per gram and having a nozzle efficiency of two-thirds, in order that the overall efficiency shall be equal to that of the propeller set, the velocity of the rocket must be about 0.8 kilometres per second.

This indicates that unless the velocity of translation is of the order of one kilometre per second (3,600 kilometres per hour), the efficiency of a rocket tends to be inferior to that of a propeller. On the other hand, it will probably not be feasible to maintain the efficiency of the screw propeller to the indicated values at such speeds on account of the centrifugal stresses, friction in manifolds, etc., but it is clear that within the *present* range of propeller speeds the possible efficiency of a rocket is much inferior. At a speed of 0.2 kilometres per second (720 kilometres per hour) the efficiency of a rocket cannot exceed about 7 per cent., and at half a kilometre per second about 16 per cent.

Importance of High Jet Velocity

The paramount importance of large velocity of discharge is obvious. Even though the momentary velocity of actual travel be small (necessitating for the time

being a low thrust efficiency) this is still true. Goddard indicates that the range describable varies as the seventh power of the jet velocity, and, while this is only an approximation, it is because the relation of the range to this velocity is of this order and because the present values of this velocity may be increased that the rocket possesses any prospects at all. This is Goddard's most essential contribution to the subject.

Air Resistance

The resistance of torpedo or fish-shaped rockets is complicated by the disturbances due to the jet. Richardson has made some experiments, but much more is required to be known. Since it is essential to exceed the velocity of sound in air in order to get fair thrust efficiency it seems that nose resistance without tail compensation should be considered and that, generally speaking, the resistance will vary as the square of the velocity. Ballistic resistances show a rather sudden jump at velocities close to that of sound on account of the creation at that velocity of a full diameter wake, and experiment has yet to decide the best nose form. Probably the pointed type is better than the bull nose form, since the latter, however excellent for airships and fuselages, presupposes a tail compensation of pressure.

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CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—Mr. W. O. Manning, in his letter in the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY for July, 1933, voices a popular but erroneous belief that it was the coming of light power that gave to the Wrights the opportunity to fly that had been denied to their predecessors.

Although, as Mr. Manning very rightly says, the Wright aeroplane engine was not available in 1848 for Stringfellow, I would remind him that other engines of lighter weight per horse-power had been built previous to the Wright engine by Maxim and by Manly. Both Maxim and Langley, who used these engines when they built their power-driven machines in 1891 and 1903, had the knowledge of the earlier work of Sir George Cayley and of Stringfellow, but the possession of this knowledge and adequate power did not enable them to fly. There seems to be no ground for supposing that they would have succeeded had they possessed the Wright aeroplane engine instead of the lighter engines which they did possess.

It was in the decade preceding the Wrights' invention of their aeroplane that at least two Governments, encouraged by the fact that adequate power was then available, subsidised the building of flying machines and the attempts to fly them. They failed, not for lack of power, but because of their lack of knowledge of how to apply and control that power. In order to fly it was necessary to make efficient wings, produce efficient propellers, direct the thrust in the right direction, and manipulate the machine in such a way as to enable the man not only to rise in the air, but to remain in sustained flight and subsequently to land so as to fly another day.

Perhaps Colonel Lahm might not have drawn Mr. Manning's criticism had he referred to the Wright Brothers as the inventors of the first successful airplane, but the word " successful," to my mind, is included in the term " airplane " in the same way that " flight " is now recognised, since the Gorell Committee, as being confined to actual flight and is not applicable to unsustained hops or to flights assisted by towing from a car.

I would therefore submit, with all respect to Mr. Manning's long experience, that Colonel Lahm, in referring to the Wright Brothers as the inventors of the airplane, is justified in this expression without requiring the qualification " successful " or " capable of flight " to be added after the word " airplane."

Yours faithfully,

GRIFFITH BREWER.

THE BEHAVIOUR OF FLUIDS IN TURBULENT MOTION

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Sir,—I read with great interest the lecture of December, 1st, 1932, on " The Behaviour of Fluids in Turbulent Motion," by Mr. Fage, as I have followed for many years his very valuable contributions to the modern experimental hydrodynamics. I especially appreciated in his last paper the statement that the fully developed turbulence is essentially three-dimensional even if the mean motion is two-dimensional. I came to the same conclusion by some theoretical statistical investigations on turbulence which I recently carried out where the assumption of a two-dimensional turbulence failed.

I am sorry that I cannot completely agree with another statement in the paper. The lecturer writes the following:—" Some attempts have been made to determine the state of flow in the neighbourhood of flat plates and circular cylinders, but the solutions obtained have failed to indicate the commencement of eddying motion."

I cannot say as to whether he is referring in this sentence to my investigations of the stability of the laminar flow along a flat plate lying in the direction of the stream (" Nachrichten d. Ges. d. Wissenschaften z. Göttingen," p. 21, 1929), and the later application of my method to the flow inside a rotating cylinder by Dr. Schlichting (" Nachrichten d. Ges. d. Wissenschaften z. Göttingen," p. 160, 1932). In any case, I cannot approve of the criticism.

In the above mentioned paper of mine, it has been shown that certain oscillations or, as Mr. Fage may say, periodical eddies, may be superposed on the basic flow at the proper Reynolds numbers without dying out and even with increasing strength. Thus, the instability of the mentioned laminar flow under certain circumstances agreeing in a satisfactory manner with the experiments has been proved. On the other hand, also the wave length of these oscillations or the spacing of the eddies and the travelling velocity of the latter have been given. It would also be possible to calculate the velocity distribution in the mentioned eddies. Therefore, I cannot see why the theoretical investigations have failed to indicate the commencement of eddying motion.

W. Tollmien,

California Institute of Technology.

Sir,—I wish to thank Dr. Tollmien for his written contribution to the discussion, which was inadvertently omitted in the general reply in last month's Journal. The criticism there made was justifiable, and mention should have been made in the paper of Dr. Tollmien's theoretical prediction of the breakdown of laminar flow.

Yours faithfully,

A. Fage.

REVIEWS

The Measurement of Air Flow

By E. Ower, B.Sc., F.R.Ae.S. Published by Messrs. Chapman and Hall. Price 15/-. 2nd Edition.

This book deals with various methods of measuring air flow, and the principles of the pressure tube anemometer, plate orifice, Venturi tube, the vane and hot wire anemometer, etc., are discussed with the aid of much mathematics. There is also a chapter on manometers and another on examples from practice.

The effect of the author's experience as assistant in the Aerodynamics Department of the National Physical Laboratory can be seen in the way the subject matter is dealt with, and the book will appeal more to the research department of the firm concerned rather than to the engineer, who does not usually require such detailed knowledge of the instruments he uses. The theory of the watch is usually only vaguely understood even by those who use the instrument constantly for scientific research purposes.

The book is useful as it contains a complete description of modern methods of measuring air flow, written by an author who is an authority on the subject, and those who are interested in this subject scientifically will find the work a valuable addition to their library.

An Introduction to Aeronautical Engineering. Vol. III.—Properties and Strength of Materials

By J. D. Haddon, B.Sc., A.F.R.Ae.S. Sir Isaac Pitman and Sons, Ltd. Price 8/6.

This work is a low-priced text-book written in simple language, and is intended as an introduction to the subject with which it deals. Calculus has been avoided almost entirely, but it is pleasing to see that the author lays stress on the importance of a knowledge of calculus, as this latter subject is essential if a student is to progress beyond this book.

The structure of matter is well dealt with and the student is encouraged to think of the effect of strain on the molecules of the strained material—a point which might well be copied in more advanced works. Sufficient information is given on Metallurgy to enable the student to obtain a preliminary idea of this subject. Testing is well and clearly dealt with, and the effect of stress and strain is explained with examples drawn from practical construction. Beams, the stresses produced in them by loading, struts, and all the other subjects one expects to find in a book of this type are discussed, and the author shows considerable mathematical ingenuity in avoiding the usual calculus proofs.

The upper photograph on the frontispiece is not at all clear, and in future editions it should not be difficult to find a photograph showing the effects of elastic instability in a much more decided manner. There is also a curious error on page 1, as the difference between the solid and liquid states of a material do not depend on the distance between the molecules. The addition of a bibliography of more advanced works would be an advantage.

These are, however, small points and do not affect the fact that the book is a very valuable and useful introduction to the subject with which it deals. It can be particularly recommended to ground engineers and aircraft mechanics who are anxious to improve their status in the industry. These will find, in many cases, all that they wish to know.

Materials of Aircraft Construction

By Prof. F. T. Hill, F.R.Ae.S., M.I.Ae.E. Published by Sir Isaac Pitman and Sons, Ltd. Price 20/-.

This work deals exclusively with the materials of aircraft construction, and the subject is appropriately introduced by a chapter on mechanical testing. It is founded necessarily on Air Ministry practice, and it deals, not only with metals but also with timber, which is now considered to be more advantageous than metal for the construction of certain types of aircraft; though, until recently, it was the opinion of many designers that metal construction would become universal. The introduction of the chapter dealing with timber and glue is therefore well justified.

The book may be considered as an analysis of standard aircraft material specifications. The author deals with each specification in detail, explains the reason for its existence, and does not hesitate to criticise when he considers it necessary. He is obviously dealing with a subject he understands thoroughly, and the work fills a very distinct gap in aeronautical literature.

There is little to criticise, but the author's definition of Proof Stress on page 10 cannot be passed without comment. As it stands, any load up to that producing a small permanent extension would comply with his definition. The correct definition is, however, given on page 12. In dealing with high manganese steel, he omits to mention the remarkable way in which this material hardens when deformed. It is this property which makes these steels unmachinable and which gives them their high resistance to wear. Normally, this steel is fairly soft. Further, the author's statement that a bullet-proof steel is unmachinable

is not necessarily correct. Such steels are not usually very hard or they would splinter under the impact of the projectile. There are proof-reading errors on pages 100 and 176, and the author is occasionally at fault in his choice of an expression. For instance, " All cleaning up of brazed joints should be forbidden if practicable," on page 181, actually means the reverse of what he intends it to mean.

Apart from these minor blemishes, the book is one which can be thoroughly recommended and should be in the hands of all those who have to deal with aircraft material specifications. Few of those engaged in the aircraft industry understand very much about the specifications they do not normally use, and an authoritative guide of the type of this book fulfils a distinct want.

It should be noted that the book contains an excellent bibliography, a feature of which is the frequent reference to the Journal of The Royal Aeronautical Society.

Flying

By Major-General James E. Fechet. Published by Messrs. Bailliere Tindall and Cox. Price 5/6.

This book is one of a number published in America under the heading of " A Century of Progress Series," and is written principally for the purpose of giving the ordinary individual some information on the progress of aviation.

As the space allowed to history only amounts to some 31 pages it is obviously only possible to present a rough outline, but the author has succeeded in presenting the more important facts clearly and correctly. It is interesting to note the importance justly ascribed to the work of Sir George Cayley.

There is a short chapter dealing with aircraft in the Great War, written, naturally, from the American point of view, and others dealing with flight instruction, famous pilots, modern aircraft, and finally, a chapter on the future of aviation.

This latter chapter rather invites criticism, but one is rather disarmed by admiration for the courage of an author who dares to be a prophet. However, he is not very unreasonable and it is probable that many of his forecasts will eventually be fulfilled.

The fact that such a book can be sold is evidence of the increasing interest taken by the general public in aviation matters. While it contains nothing of interest to the technician, it should make a direct appeal to those who, having discovered that the aeroplane has become a practical instrument of transport, desire to know something about its history and development.

The 562nd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

SIXTH MEETING, SECOND HALF, 68TH SESSION

A meeting of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, March 9th, 1933, when a paper on "Engine Cooling Research," by Mr. R. McKinnon Wood, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S., was read and discussed.

In the Chair: Mr. D. R. Pye (Deputy Director of Scientific Research at the Air Ministry).

The CHAIRMAN: Mr. McKinnon Wood was the Head of the Aerodynamics Department at the Royal Aircraft Establishment, had been a member of the Council of the Society for several years and had delivered several distinguished lectures to the Society.

It was perhaps significant that one of our leading experts in aerodynamics should present a paper on engine cooling. It was, of course, a commonplace that in an ideal world an aeroplane and its engine should be conceived as a single unit in the mind of the designer, and the nearest approach to the realisation of that ideal in practice, one supposed, was the Schneider Trophy seaplane. It was a good thing to be made, from time to time, to think a little in advance of the achievements of practice, and Mr. McKinnon Wood in his paper had done so. He had carried the conception of the streamline engine to its logical conclusion, and to the point at which, one might say, the aeroplane had so far swallowed the engine as to leave nothing but "a smile on the face of the tiger."

ENGINE-COOLING RESEARCH

BY

R. McKINNON WOOD,

O.B.E., M.A., ASSOC.M.INST.C.E., F.R.AE.S., M.I.AE.S.

Papers were read before the Society in October, 1930, by Major F. M. Green ("The Resistance of Air-Cooled Engines"), and by Mr. H. C. H. Townend ("The Townend Ring"), and in March, 1931, by Captain A. Swan ("Recent Developments in Engine Cooling"). These papers were mainly concerned with developments which had reached the stage of flight tests. The title allotted me is a wide one, but I think I am interpreting the intention of the Council in confining my attention to the air-cooled engine of the future as I imagined it a few years ago. I am indebted to the Air Ministry for permission to describe the results of research conducted at the Royal Aircraft Establishment with the objective of developing this conception and assessing its value; the deductions drawn from this work and the opinions expressed in this paper are, of course, purely my own. I claim no novelty for the basic ideas, which have in fact been embodied in a well-known motor car.

The air-cooled aircraft of the past, with its bare cylinder heads, is an abomination to the aerodynamically minded. Its speed falls far short of that of the aeroplane with the water-cooled engine, at the speeds of the order of 200 miles

an hour which now obtain. It is not possible to estimate exactly the fraction of the developed horse-power which is spent in cooling by exposed cylinders, but the figure appears to be about one-third at a speed of 180 miles an hour. The comparable figure for a water-cooled engine with a retractable radiator seems to be about one-eighth. These figures are in respect of drag alone; the weight involved in cooling has not been taken into account. The water-cooled installation is heavier, but this greater weight is roughly counterbalanced by the greater supply of fuel demanded by the air-cooled engine. The designer has long sought to enclose the engine in a smooth exterior. Major Green illustrated his paper with a photograph of a model streamline body enclosing a radial engine designed and tested at the R.A.E., in 1917. Since that date much work has been done on the enclosing of air-cooled engines, with helmets and with cowls of the form popularised as the " N.A.C.A. cowl." In-line engines have been enclosed on light aircraft as, for example, the " Gypsy " in the " Moth." Mr. Townend has produced his very pretty invention, giving substantially the same results as the N.A.C.A. cowl and helmets, but leaving the engine easier of access. The result has been an appreciable increase in the speed of air-cooled aircraft. An analysis of the available relevant data from performance tests indicates that the air-cooled aeroplane is still behind the water-cooled—the Townend ring roughly halves the difference.* Moreover, it appears that all the cowlings and rings that have been devised increase the cylinder temperatures appreciably, and that with the development of supercharging and increase in power from other causes designers may be hard pressed to provide enough cooling, and cylinder dimensions are limited by this factor.

Some time ago the writer made an estimate of the power which must necessarily be expended in air-cooling, and reached the conclusion that it was very much less than that spent in the best installations in use, either air-cooled or water-cooled, excepting only such aircraft as the Schneider Trophy racers—in which the heat is transferred through the surface of wings, body and floats. The estimate represented an ideal which would never be reached in practice, but one to which approximation should be possible. It assumed streamline motion throughout.

The conception of the air-cooled engine of the future was on the following lines. The cross-section area would be reduced until the engine would conveniently fit into a body of good form and of the maximum sectional area demanded by the purpose of the aircraft. Reduction gearing would assist this decrease of cross section, for the large diameter of existing radial engines is related to the use of a direct drive. A lengthening of the airscrew shaft might also help in adapting the engine to the streamline. The cylinders would be generally of existing form, but, speaking from a purely aerodynamic standpoint, " side " valves behind the cylinders should aid greatly in carrying through the conception to the best result by leaving the cylinders with clean heads for cooling purposes. The cylinders would be given the maximum practicable area of fins and enclosed in sheet metal jackets through which the cooling air would flow, thus avoiding the waste effort of carrying surplus air through the body of the aircraft. The ducts would be carefully shaped from entrance to exit to minimise loss of energy by avoiding sharp curves and rapid expansions. The circulation would be partly or wholly produced by an airscrew fan driven by the engine through gearing, revolving considerably faster than the airscrew—at between 3,000 and 4,000 r.p.m.

It will be seen that there are two separable ideas here. Firstly, the jacketted engine with carefully streamlined passages. Secondly, the introduction of the fan; and the latter can again be separated into the introduction of the fan as an auxiliary and the use of the fan to give the sole motive force.

* It is, of course, possible that the air-cooled aircraft are inferior in performance because their engines are radial and so of larger frontal area.

The first idea is not new in aeronautics. Guide plates have been used from early times; they are used in the Moth. Both the National Advisory Committee in the N.A.C.A. cowl and the Royal Aircraft Establishment in helmets found it profitable, and, in fact, necessary, to introduce internal guides or linings. Any novelty that is in the proposal lies in carrying the lining to a logical conclusion and in the further proposal that the design be thrown upon the shoulders of the designer of the engine, which would be sold complete with jackets and fan and the greater part of the inlet and outlet ducts. This proposal has partly been anticipated by the interest which the producers of engines have taken in the Townend ring as part of the engine. It is obvious that the goal put forward is not easy of attainment; valve gear and sparking plugs present serious obstacles to the design of ideal passages. But surely the prospects of approaching the ideal will be highest when the problem is attacked in the same office as the other features of the engine. Moreover, much fewer engines than aeroplanes are designed, and it is better to concentrate the difficulties where their solution in each specific case will have the widest application. The objective sought is that each engine will be sold with a guarantee that its cooling will be adequate and the power spent in cooling of the standard of the time, given a minimum of effort and aerodynamic sense from the aircraft builder.

The last sentence has implied the use of the fan; for, in fact, the guarantee could not be given if reliance had to be placed on a flight-induced flow. This second idea is about as old as the motor car; but a little more thought must be put into the aero-engine fan. The fan may conceivably meet four needs. Firstly, airscrews can be highly efficient and, although it may seem that flight-induced flow is a gift, it is not clear from first principles that flight flow through a body does not entail a large expenditure of energy in relation to the work done in overcoming the resistance in the passage. The relative merit of fan flow and flight flow probably depends upon the amount of flow required, the former being better for larger flows. The writer was inclined to the opinion that the fan would be distinctly more efficient for the quantity of flow required to cool an engine. Secondly, it has been already remarked that we are close to the limit of the cooling we can supply in existing cowled installations. The fan may extend this limit almost indefinitely. Thirdly, the fan gives a means of adjusting the cooling, should it be inadequate or excessive in a specific case, and one which is more easy and more potent than the rearrangement of cowling. Fourthly, the fan offers an automatic regulation of the cooling to suit the flight speed. The larger power expended in cooling air-cooled engines in fast aircraft is largely due to excessive over-cooling at top speed. Water-cooled installations are fitted with shuttered or retractable radiators, primarily perhaps to avoid the danger of the water freezing, but, at least incidentally, having an appreciable effect on top speed. The result is far from perfect. The retractable radiator is the best form in common use, and the power spent in cooling at a top speed of 180 m.p.h. is about three times that spent on climb at 90 m.p.h., the radiator being retracted to give the requisite cooling. Ideally the power should be the same. Perfect regulation and constancy of power spent should be obtained in an air-cooled system in which the circulation is entirely due to the fan. Some form of shutters could be fitted to cowled air-cooled engines. This might prove a profitable line for immediate development, and the " Rapier " engine suggests itself as one which could most readily be fitted with shuttered cowling. For the radial engine the fan might prove simpler, and it has the merit of giving a fair degree of regulation automatically.

From the above reasoning it would appear that the fan should provide the whole motive force. This should give perfect regulation and, assuming the writer's initial hypothesis that fan flow costs less than flight flow, this system should be more efficient on climb as well as at top speed. But it will probably prove difficult to design passages through a body such that the air will flow

through without loss at entry and exit under the action of a fan, and yet will not flow through in fair quantity of its own accord; it may in fact prove impossible.

The ideas discussed have shown a prospect of marked improvement of the air-cooled aeroplane based on a number of very debatable points which cannot be decided by debate, but call for experiment. Preliminary experiments have been made at the R.A.E. by Mr. Hartshorn. I have only space to describe the more interesting tests and results.

The first series of experiments were made with a finned steel cylinder, about 6ins. in diameter and 6ins. long, enclosed in a duct built of wood. The duct started with a rounded entry, divided symmetrically round the cylinder and rejoined, and terminated after expanding in a large box. In the box the air first passed a large area of gauze and then through two sharp-edged orifices into a second large chamber, from which it was exhausted by a centrifugal blower.

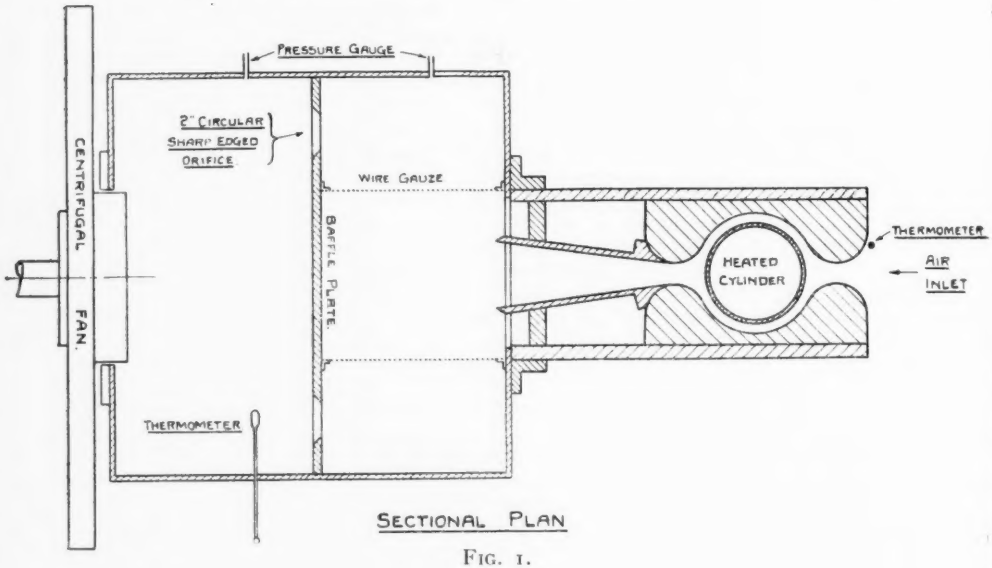


FIG. 1.

The arrangement is shown in Fig. 1. From the pressure in the first and second compartments, the flow of air and the loss of energy could be found. The cylinder walls were heated by steam from an electrically-heated boiler below the radiator. The electrical input was adjusted to keep the pressure in the cylinder constant and approximately atmospheric. By this ingenious arrangement, due to Dr. G. P. Douglas, the walls were kept at a uniform known temperature and the heat flow was measured by the electrical input required. The arrangement is shown in Fig. 2. Similar tests were made with a finned plate about 8ins. square. In both cases the fins were 1in. long and of 0.25in. pitch, giving ratios of cooling surface to base area of 10.6 and 9.2 respectively. The tests gave the following figures, assuming the temperature of the inside of the cylinder walls to be 250°C. above the temperature of the atmosphere:—

	Finned cylinder.			Finned plate.		
Average speed between fins (f.p.s.)	50	100	150	50	100	150
Heat flow in h.p.	14.5	22	(27.5)	10.5	16	20
H.p. to circulate the air	0.05	0.37	(1.25)	0.02	0.17	0.55

The figures in brackets have been extrapolated. The figures relate to one square foot of cylinder surface.

Now the flow of heat required does not appear to be known with any certainty. It has been measured for a number of modern water-cooled engines, but I know

SKETCH OF HEATER IN TUNNEL

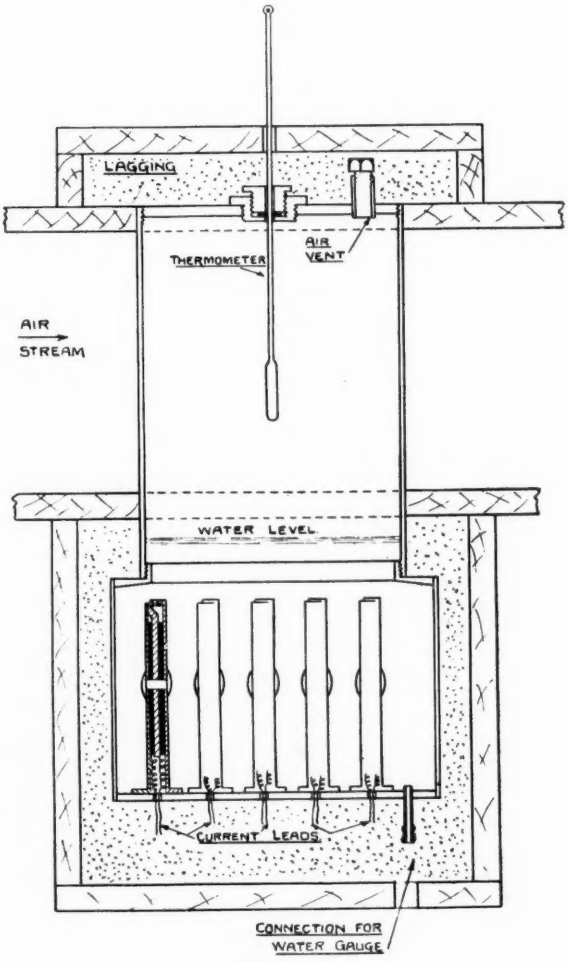


FIG. 2.

of no measurements made with air-cooled engines. The heat flow used to be assumed equal to the brake horse-power. Major Green, in the paper quoted in my opening sentence, puts it at " rather less." The latest measurements at the R.A.E. on a water-cooled engine gave a figure of roughly a half, and it seems that this ratio should have fallen as piston speeds have risen. I should expect

it to be less for an air-cooled than for a water-cooled engine, and I think that it is safe to take the heat flow through the cylinder walls equal to half the brake horse-power.

It appears to be typical of the air-cooled engine of to-day, in the larger sizes, that heat flows through one square foot of cylinder surface for each 50 h.p. developed. So the heat flow required is about 25 h.p. per sq. ft. If it be assumed that the finned cylinder of the experiments represents two-thirds of the cylinder surface and the finned plate the remaining third, it will be seen from the above table that we required an average speed of flow of cooling air of 150ft. per sec. (roughly 100 m.p.h.). It will also be seen that one horse-power is required to circulate the air. This, however, only takes account of energy consumed in the parts represented in the model. In addition there will be losses at the fan and losses in the entry and exit ducts. Assuming an overall efficiency of 50 per cent. (remembering that it should be possible to design a fan of 75 per cent. efficiency or considerably higher), we reach a total of 2 h.p., which is 4 per cent. of the brake horse-power.

Engine designers may object that 250°C. is too high, and wish the limit placed at 200°. I am inclined to believe an average temperature of 250° is not too high if the temperature is fairly uniform and no much hotter spots occur; but I base this belief on a very limited experience of flights of an aeroplane with a cowled-in Jupiter engine. I have actually chosen 250° in the first place, because the experimental data is then directly applicable. To predict for 200° would need extrapolation. The flow speed required would be about 200ft. per second, and the horse-power spent in cooling would become nearly 10 per cent. of the b.h.p. It is clearly important to know the permissible temperature fairly exactly and to avoid any undue margin of safety.

Referring back to the table of experimental results, it will be noticed that the power expended in cooling varies rapidly with cooling speed—roughly as the cube. The heat flow varies slowly with the speed; in fact, it increases about 50 per cent. when the speed is doubled from 50 to 100ft. per sec., and doubles when the speed is trebled. This is due to two causes. Firstly, the heat flow with a given difference of temperature between surface and air varies less than in proportion to the speed. Secondly, there is a considerable drop of temperature along the fins and this drop increases as the heat flow is increased by raising the speed. The metallic resistance to the heat flow from cylinder to cooling surface is an important factor. The following figures were estimated for the finned cylinder:—

Flow speed (ft. per sec.)	50	100	150
Ratio of average surface temperature to base temperature	0.71	0.64	0.57

From this analysis it is evident that the use of a metal with a higher conductivity than steel (*e.g.*, aluminium or copper) would have a big influence on the economy of cooling. It is also clear that the maximum possible cooling surface should be provided. The two desiderata are likely to be in conflict, since steel can be worked thinner than aluminium. It should, however, be noted in this connection that there is a limit to the closeness with which fins can effectively be spaced, as has been shown by recent experiments in the United States of America. The heat extracted by the air falls off rapidly when the surfaces are brought too close together, and Mr. Pye has related this phenomenon to the mingling of the boundary layers.

It is of interest to study the experimental results in the form of the usual non-dimensional coefficients of aerodynamics and in accordance with Osborne Reynolds's theory of heat transfer. This theory in its simplest form states that the rate of heat flow is

$$H = C_p \, T \, k_F \, \rho \, SV$$

while the power consumed by the frictional resistance is

$$P = k_F \rho S V^3$$

where C_p = specific heat of air at constant pressure in work units
T = temperature difference between surface and air
k_F = coefficient of resistance
ρ = density of air
S = cooling surface
V = speed of flow.

In the practical test under discussion the coefficient k_F will not have the same value in each equation; it will therefore be convenient to denote it by k_H in the first and by k_P in the second equation. The figures at 100ft. per sec. are:—

		Flat plate with turbulent layer.		
		k_H	k_P	k_F
Finned Cylinder	...	0.0033	0.0079	0.0036
Finned plate ...	...	0.0023	0.0044	0.0036

The Reynolds number in terms of the hydraulic mean depth (twice area of section divided by perimeter) is 7,500.

It will be seen that the ratio of power spent to heat extracted at a given speed is 2.4 and 1.9 times the theoretical ideal ($k_P = k_H$), and that the cylinder extracts nearly half as much heat again as the plate. The ratio of resistance to heat flow is a little greater in the cylinder, but, in effect, the cylinder is far more efficient because of its higher heat coefficient, and the finned plate takes roughly twice the power for the same flow of heat. It is therefore better to cool from curved barrels than from a flat head. The figures suggest that a large part of the flow occurs with a laminar boundary layer, particularly in the case of the plate.

Passing now to the second series of experiments designed to investigate the second idea, the introduction of the fan, it was decided to idealise the model to the simplest form which would include the essential features of the problem, but recognising that there were certain overall dimensions which must be quantitatively to scale. For the first stage, which is now completed, the airscrew was omitted. The body used was a solid of revolution. The cylinders were represented by a ring of gauze. The area of this ring, and the resistance of the gauze, were designed to represent the section area and resistance of the passages through an engine designed in accord with the general conception. An eight-bladed fan was designed to impart the required power with fair efficiency, the blades moving in an annulus of the same dimensions as that of the gauze. The fan was driven by a small A.C. motor housed in the body, and provision made to measure the torque (by reaction) and the revolutions. Small pitot tubes and static pressure holes were inserted to obtain the speed of flow, the thrust of the fan, and the resistance of the gauze. The annular air passage was parallel from ahead of the fan to some distance behind the gauze, and generally parallel from the entrance. The annulus enlarged to the exit, a little ahead of the maximum section of the body. Fig. 3 illustrates the general arrangement and shows a particular form tested.

The experiment resolves itself into two parts—the study of flight induction and the study of fan induction (alone or combined with flight induction). The same model was used for both, the fan being removed when not required. The only alterations were in the form of the duct and consequent adjustment of the external form. Clearly a different form of duct is needed for the different systems. The form showing in Fig. 3 was designed for experiments with the fan. Without the fan, the flow through the duct was found to be at 0.60 of the flight speed. This model is shown as Model 1 in Fig. 4. Models 2 and 3 represent successive stages in inducing a greater flow, the main departures being:—

(*a*) Overlapping the outer wall of the duct so that the outlet faces more to the rear.
(*b*) Expanding the duct towards the outlet.

In addition a slight overlap was introduced at the nose. Model 4 was the original design for flight-induced flow. It has a large expansion and a big overlap (or scoop) at the entry. The drag was very high and the flow inferior to that through No. 3. This suggests that the " scoop " produces drag without flow. It was probably wrong in conception, but the " scoop " idea is very widely held.

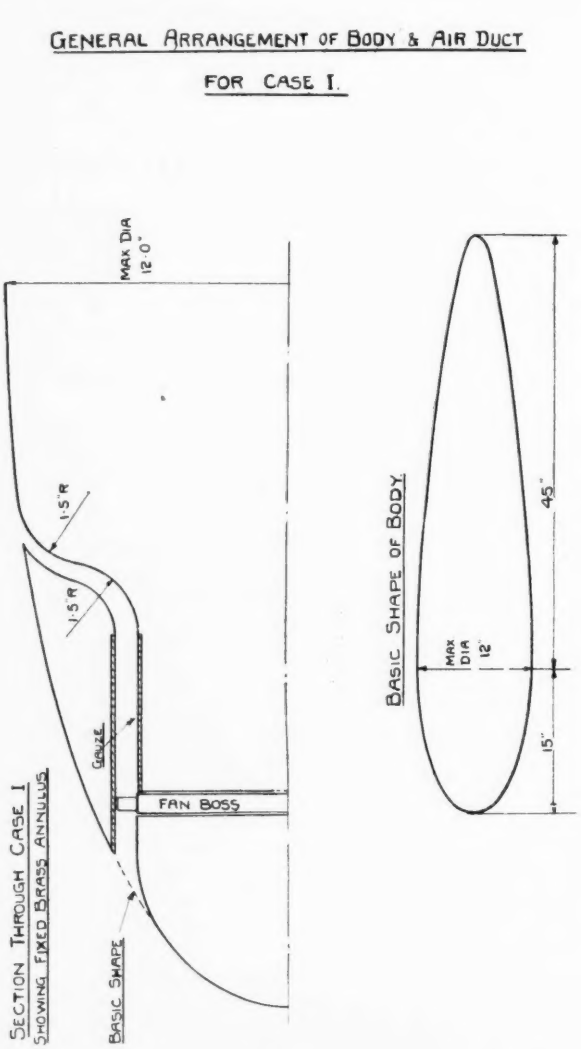


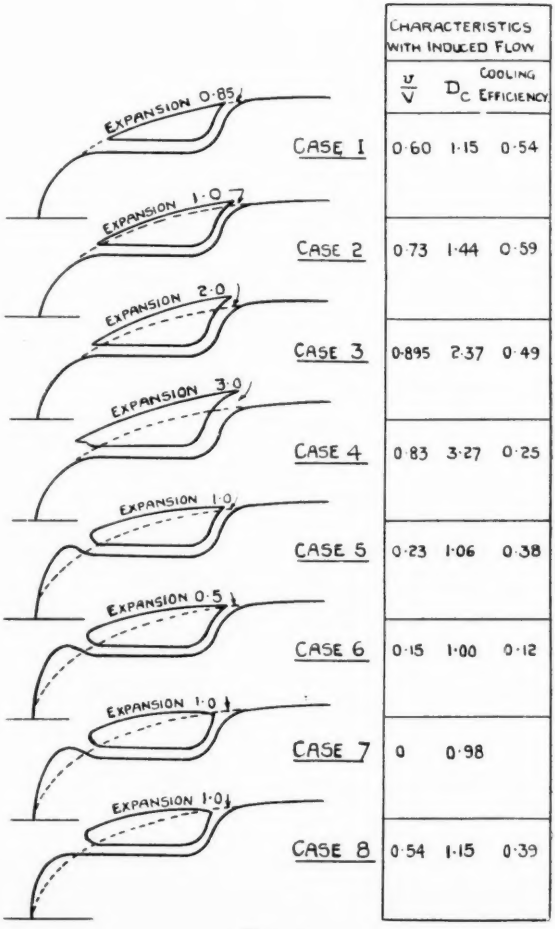
FIG. 3.

The results obtained were:—

Model No.	1	2	3
Flow ratio	0.60	0.73	0.90
Drag per sq. ft. cross section at 100 ft./sec.	1.15lb.	1.45lb.	2.35lb.

The corresponding drag of the smooth body without passages was 0.7lb. The investigation is far from exhaustive, but it indicates that it is very difficult to get a flow ratio as high as unity. Now from the previous discussion it appears that a speed of 150 to 200ft. per sec. is needed, and the higher speed is approximately the speed in the slipstream when climbing at 100 miles an hour. It seems therefore that flight induction is near the end of its tether.

DETAILS OF DUCTS.



	Characteristics with Induced Flow		
	$\frac{v}{V}$	D_C	Cooling Efficiency
Case 1	0·60	1·15	0·54
Case 2	0·73	1·44	0·59
Case 3	0·895	2·37	0·49
Case 4	0·83	3·27	0·25
Case 5	0·23	1·06	0·38
Case 6	0·15	1·00	0·12
Case 7	0	0·98	
Case 8	0·54	1·15	0·39

FIG. 4.

Mr. Hartshorn has made an interesting analysis of the drag. The resistance of the gauze is approximately $\frac{1}{2}\rho v^2$ per unit area, where v is the speed through the duct, and a power of $\frac{1}{2}\rho a v^3$ is therefore necessarily expended, where a is the duct area. Now the power actually spent in cooling is the product of the flight speed and the excess of drag over that of the ductless body. The ratio provides an efficiency of the cooling system. The figures are 0.52, 0.60 and 0.48, and they are such that there is not very much prospect for improvement by the use of a fan. The scope for the fan, therefore, lies in increasing the flow ratio, in securing the advantage of automatic regulation of cooling with flight speed, and in making it easy to obtain ample cooling.

When the fan is introduced the total torque power expended in driving the body through the air and in cooling the engine is

$$(1/\eta)\ DV + P$$

and the virtual drag per sq. ft., of body section at 100 ft. per sec., is obtained by dividing this expression by

$$10^{-4} A V^3 \eta$$

where η = airscrew efficiency.
D = drag of body.
V = flight speed.
P = power input to fan.
A = maximum cross section area of body.

It is convenient to express the results in this way for comparison with the figures already quoted.

Model 1 with fan yielded the following results, assuming an airscrew efficiency of 0.8:—

State of Flight.	nd/V	v/V	v/nd	D_a	D_v	η_f
Climb, full power ...	1.00	1.00	1.00	0.85	2.7	0.62
Level, full power ...	0.55	0.66	1.20	1.1	1.3	0.50

where n = revs. per sec. of fan.
d = diameter of fan (7.4 inches).
V = flight speed.
v = flow speed over cylinders.
D_a = actual body drag per sq. ft. at 100ft. per sec.
D_v = virtual body drag per sq. ft. at 100ft. per sec.
η_f = efficiency of fan.

The first column of figures is selected as typical of the two states of flight of a high performance aircraft: the second gives the flow ratio we have been discussing: the third gives an alternative flow ratio which is roughly indicative of the change in flow from climb to level speed, since the r.p.m. will not change much: the fourth shows how the fan decreases the actual drag, which was 1.15 without fan, while the fifth shows the virtual drag on which the performance rests: the last column shows that the fan is reasonably efficient, though not as good as might be expected; a higher efficiency should obtain full scale. It will be seen that the fan serves to halve the virtual drag coefficient at top speed. We may, however, fairly subtract the drag of the ductless body, 0.7, and say that the coefficient of the drag involved in cooling has been reduced in the ratio of 2 : 0.6. The top speed is assumed to be twice the climbing speed and the thrust horse power expended in cooling is therefore in the ratio 2 to 4.8, whereas with equal coefficients it would have been 2 to 16.

This experiment was made with a model with a high proportion of flight-induction. Attempts were made to reduce this, firstly by turning back the entry till it was normal to the body surface (Model 5, figure 4). To avoid serious loss of energy at entry the edges were well rounded. This gave a flow ratio

of 0.23. Secondly, the duct was contracted towards the exit and the flow ratio reduced to 0.15 (Model 6). Thirdly, a hollow was introduced in the body contour to give a local rise of pressure at the exit and the flow reduced to zero (Model 7).

The corresponding table for this last model is:—

		nd/V	v/V	v/nd	Da	Dv	ηf
Climb	...	1.12	1.00	0.89	1.0	3.3	0.64
Level	...	0.62	0.55	0.89	1.1	1.5	0.64

It will be seen that the regulation is perfect, but that the performance is definitely inferior. It appears that there is no advantage in taking the necessary pains to provide a non-flight-inductive passage, unless there be any merit in keeping up the temperature of the engine.

One further point deserves notice. The tests with fan have been discussed on the basis that a flow ratio of unity is needed on climb and Mr. Hartshorn failed to reach this figure with flight-induction. The figures I have given in the two cases are not comparable. Comparison of the results of experiments at the same flow shows that the two systems are of equal merit up to a flow ratio of 0.75, but that the fan system takes 15 per cent. less power for cooling at a flow ratio of 0.9.

To sum up, it has not been proved that fan induction is more efficient than flight induction for the rate of flow required. On the other hand, a strong case can be made for the fan as a means of giving more cooling if flight induction fail: as an easy means of adjusting the cooling; and, most important, as providing a large measure of automatic regulation with flight speed which has an important influence on the top speed.

The work done in forcing the air over the cooling surfaces, even in the idealised model of our experiments, is much greater than the ideal skin friction loss and here, in particular, further study is required and the problem needs to be studied in closer relation to the practical details of engine design. In addition it is important to inquire into every possible means of reducing the speed of flow required for cooling, since the power consumed varies roughly as the cube of the speed. The road is clearly a long one and we have only passed a few milestones. I think it is worth travelling.

Appendix

On the Conditions Governing the Flow Through a Body

Froude's Airscrew Theorem is well known. Half the acceleration of the airscrew stream takes place ahead and half behind the airscrew. This theorem may reasonably be applied to a disc of gauze: the air which flows through the gauze will have received half its final retardation when it reaches the gauze.

If the gauze disc be inserted in a tube, the tube will impose a parallel flow along the greater part of its length and the retardation will take place entirely ahead of the tube. The walls of the tube behave, in fact, like an aerofoil; which is, so to speak, dominated by its trailing edge. The ideal shape for the entry to the tube then is a flared-in form adjusted to suit the divergent stream. The outward flare, which is so commonly seen on air-intakes, such as ship ventilators, does not increase the flow, but does increase the drag.

The flow can be increased by expanding the tube behind the gauze and if a parallel portion be added after the expansion, the emergent flow is parallel and the flow can be calculated. If the resistance of the gauze be very low, the speed may there exceed the speed of motion of the tube relative to the bulk of the air.

It then becomes advantageous to flare out the entry to avoid " shock at entry." We have now—removing the gauze altogether—a free air venturi tube, and we can calculate the flow through it, approximately, if we know the losses in the expansion.

Incidentally, it follows from this argument that a honeycomb radiator should not be represented in a wind tunnel test by a plain piece of gauze, but the gauze should be surrounded by a frame of thin sheet.

If the tube be placed with its outlet in a position where the pressure of the air is reduced by the presence of some other body the flow through it is increased. On the other hand, the pressure at entry is immaterial: the flow depends on the total head at entry and any loss at entry and on no other condition there.

These general principles can be applied to the flow through a passage in a body if the dimensions are not too great and if the passage terminates in a parallel outlet directed backwards along the body.

Suppose that the resistance in a passage is concentrated at a point where the speed is v, and that the air emerges at speed av at a point on the body at which the pressure is p. The emergent flow is parallel and so its pressure is also p.

Let $\frac{1}{2} k\rho v^2$ be the concentrated resistance.
p_0 be the atmospheric pressure.
V be the flight speed.
Then $p+\frac{1}{2}\rho a^2 v^2+\frac{1}{2} k\rho v^2 = p_0+\frac{1}{2}\rho V^2$

and so

$$(v/V)^2 = (p_0+\tfrac{1}{2}\rho V^2 - p)/\{(a^2+k)\tfrac{1}{2}\rho V^2\}$$

The influence of total head at entry and pressure at exit are obvious. Expansion towards the outlet means that a is less than unity and increases v. In practice this last conclusion is modified by the inevitable loss of energy in expansion, which may be regarded as increasing k. The increase is probably of the form $K(1-a^2)$, so that for a^2+k we have $a^2(1+K)+k+K$.

The value of K, of course, depends on the rate of expansion and the optimum value is probably about 0.25. It should also be remarked that, in practice, the pressure in the emergent stream is less than that of the surrounding air by about 0.1 $(\frac{1}{2}\rho V^2)$.

Discussion

The Chairman: He would like to ask Mr. McKinnon Wood for more information as to the correlation between the quantity of air which, with his arrangement, on the full scale, would have been passed through the duct, and the quantity of heat which had to be disposed of. Probably it was implicit in the figures given in the paper, but the problem would be clarified if the information were given explicitly.

The assumption of a mean temperature not much lower than 250° C. above atmospheric on the internal surfaces appeared to be critical for the success of the author's scheme. This would mean that they had to face a mean temperature of about 270° C. on the internal surfaces under unfavourable conditions. One must regard the cylinder surface as being in two categories—first the lubricated barrel over which the piston motion had to be maintained, and secondly, the cylinder head surface. One could not foresee what the improvement of lubricants and metals might render possible in the future, but he believed that most of the present-day practical men would say that if the temperature of the internal surface of the barrel were much above 150° C., possibly 160° C., there was serious danger of trouble. It must be remembered that the ratio of the barrel surface to the head surface was roughly 2:1, and if the temperature over two-thirds of the total area had to be restricted to 150° C. it was difficult to see how the mean temperature over the whole could be as high as 250° C. It must also be remembered that it was very difficult in practice to avoid a fairly considerable temperature range between the front and the back, and he believed that that

would still be the case even when they had the jacketed cylinder. In experiments by Mr. Heron, in America, with the ordinary direct air blast, a difference of at least 70° or 80° C. between the temperatures of the barrel, front and back, was experienced. In Heron's experiments on the head of a 4-valve cylinder—two exhaust and two inlet—when the two inlet valves were facing the air stream, there were registered, over five thermo-couples placed at critical points in the head, maximum and minimum temperatures on the head of 300° and 77° C. respectively; when the two exhaust valves were facing the air stream the range was narrowed to 190° and 112° C. The moral of that result was, that one could not rely on the conductivity of the material to distribute the heat about the head as one would like it to do, and that in order to get rid of the heat from the critical points one must rely on the direct impingement of the air on those critical points, *i.e.*, round the exhaust valves.

In Mr. McKinnon Wood's experiment to test the power necessary to circulate the air, in the apparatus shown in Fig. 1, the air passed completely round the cylinder, but in a passage streamlined as nearly as possible. The power necessary to circulate the air in that way was just about double that which would have been required if there were nothing but skin friction acting. In other words, the allowance in this apparatus for losses introduced through changes of direction of the air stream was something like 100 per cent. on the skin friction, and presumably the estimates of the power required to circulate the air in the author's design of jacketed cylinder were based on that figure of 100 per cent. over the minimum called for by skin friction only. The Chairman feared that in practice they would be faced with a power requirement much more than 100 per cent. over the minimum calculated from skin friction if they were to make use of the direct impingement of the air on the critical points—and it seemed that, with the materials at present available, the employment of some of the air in that way was likely to be essential.

Mr. H. T. Tizard (Chairman of the Aeronautical Research Committee): Mr. McKinnon Wood had dealt with a problem of great importance, which must be engaging the attention of designers of air-cooled-engine aircraft almost every day. It seemed odd that they could not obtain from performance tests sufficiently accurate figures to satisfy them as to how much power was expended in cooling the air-cooled engine in flight. It was stated in the paper that the power expended in cooling might be as much as one-third of the developed h.p. at a speed of 180 miles per hour, which meant that the air-cooling drag was about one-third of the total drag. That was a big percentage, and it was well to point out that every successful effort by designers to reduce the drag of other parts of the aircraft increased the proportion necessary to cool the engine. Therefore, Mr. McKinnon Wood's problem was going to be of even greater practical importance in the future, and one would like to hear the figure of 33 per cent. criticised, appreciating how difficult it was to find reliable practical figures. Mr. Tizard asked for opinions as to whether the proportion of drag represented by the cooling was lower in the case of air-cooled engines with cylinders in line than in the case of radial engines.

The next point was the cause of this excessive drag. Fundamentally it was due to the unavoidable shape of the air-cooled cylinder. Any aerodynamic device adopted to get over that fundamental difficulty without a forced draught, and to direct air efficiently to the back of the cylinders, could presumably be applied to the engine without enclosing it altogether in the fuselage. Mr. McKinnon Wood's proposals depended for their success essentially in the employment of forced draught by means of a fan. Large quantities of air would then have to be taken in at one part of the fuselage and expelled at another part, and it was not clear to him whether that could be done without affecting the normal flow of air over the fuselage in such a way as to increase its drag substantially.

Mr. McKinnon Wood said that there must be over the cylinder a velocity of the air of the speed of flight or climb.

Mr. Tizard said he was considering the velocity of air through the intake and exit ducts on the aeroplane. Was it necessary to take in the air at a speed roughly equal to the speed of the machine, or was it immaterial? Could one expel large quantities of air at any part of a streamlined body without increasing its drag? He was asking for further enlightenment on these points; the answers to them were doubtless contained in the author's paper. Mr. McKinnon Wood had rightly called attention to the fact that the maximum amount of cooling was required when climbing at full power. For "civil" purposes a high degree of aerodynamic efficiency was not very important under these conditions; the highest efficiency was required, however, during level flight. The result of having to provide sufficient cooling for the engine when climbing meant that the engine was likely to be over-cooled during level flight. Cooling by means of forced draught certainly provided a possible means of getting over this difficulty, and this was one of the chief merits of Mr. McKinnon Wood's proposals.

Major F. M. GREEN: Adding to what he had stated in his paper on the resistance of air-cooled engines which was read before the Society in 1930, he said that he and his colleagues were uncertain about the correct figures to take for the heat balance of an air-cooled engine. The only information that was available was some tests made by Dr. Gibson at Farnborough during the war. In order to get reliable figures for a modern engine a test had been carried out to determine the heat balance and also to find out how much energy was absorbed in cooling the cylinder when it was working at the highest temperature which was considered safe. The experiment was carried out in much the same way as in the model experiments. The cylinder was put into a sort of wind tunnel and due precautions were taken to sample the air in order to get average temperature measurements. The energy loss in the air was also measured. The heat removed from the cylinder by the air was equivalent to 55 per cent. of the horse-power developed. The horse-power wasted in the cooling air was about 4 per cent. of the horse-power developed. The temperature of the cylinder head measured on the outside was about 250° C., and the temperature rise of the air after leaving the cylinder was about 18° C. These figures agreed remarkably well with Mr. McKinnon Wood's estimate.

Experience also shows that Mr. Wood's statement that there was little margin for cooling during the climb was borne out by tests. On an aeroplane that climbed at about 70 miles an hour true speed an engine of about the size mentioned would keep reasonably cool without ring cowling, but the addition of a Townend ring was enough to bring the engine to a rather critical temperature.

Mr. McKinnon Wood mentioned that there were two ways of controlling cooling; one by varying the cowling and the other by the use of an engine-driven fan. Aircraft designers want cowling which gives the lowest drag at top speed and do not as a rule care very much what happens at climbing speed. The engine maker wants the maximum cooling at climbing speed and does not encourage the aeroplane maker to over-cowl the engine. There is therefore always a difference of view between the engine and the aeroplane designer, and a compromise results representing a higher drag than the aeroplane designer wants and less cooling than the engine designer really believes is needed. If they could take off the cowling altogether when climbing, when the drag is relatively unimportant, and put it on again when flying at top speed, they would achieve a state of affairs that would please both aircraft and engine designers. Obviously they cannot do that, but recent experiments have shown that they can probably do something better still. It is possible, by the use of suitable shutters or deflectors on an N.A.C.A. cowling or Townend ring, to secure an air speed through the cylinders rather greater than can be obtained with a bare engine. This is at the expense of a drag slightly greater than that associated with a bare engine. If these

shutters were made adjustable, then by closing them during normal flight the condition of cowling which gave the lowest drag could be restored. It would then be possible to satisfy both the aircraft and the engine designer. So far, only model experiments have been made and the question of the design of the cowling is being investigated. The speaker is of opinion that it will be quite possible to produce the device in a satisfactory way without it being unduly heavy.

The crux of the whole problem was the temperature at which the engine could be run safely. It is always possible to run an engine without danger at a temperature somewhat in excess of that which is recommended, but this will result in reducing the time the engine will run between overhauls. An engine will run fairly hot without any immediate harm arising, but the oil will sludge more quickly and eventually piston rings will stick, and that is the chief reason why engines are not run hotter than they are. Another reason is the use of aluminium alloy pistons, because if these are heated beyond a certain temperature they either pick up or soften to such an extent that the crown blows in. It is obvious that if they could increase the temperature at which they ran engines by as much as 50° then the drag could be reduced very considerably. At present he did not think that engines should be run with a cylinder barrel temperature as high as 250° C. In spite of this the position was not as bad as it sounded, because most of the heat of the cylinder was dissipated from the cylinder head, and this was always considerably hotter than that of the barrels. Dr. Gibson suggested that 80 per cent. of the heat went from the head and 20 per cent. only from the barrel. Other parts of an internal combustion engine, notably the exhaust valves, were probably nearer 750° than 250°, and suffered no harm. This is due to the improvements in the technique of making steels, and there was no essential reason why a similar improvement in the making of light alloys might not make it possible in the near future to run at higher temperatures. The production of a lubricating oil that would not sludge or stick piston rings at a higher temperature would also help matters considerably. The future of air-cooled engines, therefore, very much depends on the metallurgist, and on the chemist or whoever it is who is responsible for improvement in lubricating oils.

Mr. J. D. NORTH: He was faced with the difficulty so well expressed by Mr. Tizard, that he was unable to see any fundamental reason why the enclosure of the cylinder in a duct should be any better from the practical point of view than the method which had been adapted in the Townend ring, for example, of curing the secondary effects of the engine in producing high drag in the body. It appeared from the diagrams in Fig. 4 that the attempt had been made to preserve the superficial appearance of the streamline; the whole essence of Mr. Townend's invention, he believed, was to produce as far as possible the effects of streamline flow, showing at the same time that the superficial appearance of the streamline form was not necessary in order to attain that result. As Mr. Tizard had said, they were concerned with the disturbance of the pressure distribution around the streamlined body. He asked what was the scale h.p. of the engine used in the experiment.

From such figures as he had been able to arrive at, the h.p. for cooling was about 15 per cent. at a speed of 180 m.p.h., with a properly applied Townend ring—and that cooling was not only the cooling of the engine, but also of the exhaust and the oil, factors which would have a very important effect on, and obviously would add greatly to the difficulties of, the arrangements proposed by Mr. McKinnon Wood. If one looked at Fig. 4 in the paper one would appreciate the conception that was in the minds of the designers of the N.A.C.A. cowling, and those responsible for the design of that cowling had set out very plainly, in N.A.C.A. Technical Note No. 355, what they had had in mind; it was to produce a sort of streamlined shape over the cowling and over the engine, and to admit the air at one passage and out through another. If one removed the internal part of Mr. McKinnon Wood's structure one was left with what was in effect

the N.A.C.A. cowling. It had been demonstrated repeatedly that the overall drag of a cowling installation was not affected by even very considerable additions inside the cowling; for example, one could include a lot of extra supports, certain kinds of baffles and other things which would be expected to provide a considerable amount of resistance, but it seemed that they had no effect. At the same time, other kinds of baffling, as, for example, the deflectors referred to by Major Green, produced a large increase of drag. He did not think they could get over the fundamental fact that they had to pay for the advantage of taking the air round the cylinders. All they could hope to do was to reduce the secondary effects of this on the general flow over the body, and it seemed to him that that was done by the principle of the Townend ring.

It was somewhat difficult to decide how much of the advantages of possible drag reductions would arise from the reduced size of engine at the temperatures assumed. When reference was made to the amount of heat rejected by the cylinders one had great difficulty in appreciating why such large differences were observed as between one cylinder and another, though one could say definitely that these differences were not due to the differences in the amounts of air blowing over the cylinders. Differences as great as from 175° to 210° or 215°, for example, as between one cylinder and another, measured by thermo-couples in the same relative position, seemed to be too persistent to be accounted for by an error in measuring temperatures. If they could get the temperatures of all their cylinders down to the temperature at which three-quarters of them seemed to be prepared to work, they would need very much less cooling over the engine. A type of wind channel experiment he had carried out was to fill an engine with oil, heat the oil electrically and measure the electrical input. It was analogous to the arrangement used by Mr. McKinnon Wood, but it was found that the temperature differences were not always repeated at full scale, though one could get excellent repeats in the wind channel. It was suggested at one time that the cooling inside a cowl might be increased by installing deflectors which direct the air radially outwards, so that instead of flowing parallel, it passed across the cylinders radially outwards, as in an uncowled engine. When the deflector was fitted to the electrically heated model, it had shown a substantial heat reduction, but when fitted to the engine, however, it had shown no effect whatever.

As a further example of the difficulty of arriving at definite conclusions, Mr. North recalled some experiments in which various types of baffles were fitted. Instead of being fitted all round the engine, they were fitted round the hottest cylinder; by fitting half a baffle on each side of it, the temperature of that cylinder was reduced to a very satisfactory figure. Then it was found that a cylinder which previously had been the coolest had become the hottest. He had found great difficulty in understanding what that meant. He was not satisfied with the explanation that the whole of the phenomena were due to experimental inaccuracies, because they were repeated too regularly, and he was quite sure that the questions involved were not purely those of air flow over the engine. There was some reason at least for believing that the influence of the air flow round the ring cowling on the air intake had considerable effect on the cooling as between one cylinder and another and on the cooling of the engine as a whole.

There were a great number of pointers in the paper which would be extraordinarily helpful to all engaged in work of this sort, and all aircraft engineers would be very grateful to Mr. McKinnon Wood.

Mr. H. B. TAYLOR: He wished to amplify the remarks made by Major Green. The cylinder experimented with was about 40 h.p., and the drag, as measured by the loss of energy in the air, front and rear, was about 1-2/3 h.p. The temperature at the hottest spot would be about 250° above that of atmosphere, and the temperature of the cooling air used was 30° C.

The CHAIRMAN: Is that the rise?

Mr. TAYLOR: The actual temperature of the air entering the cylinder cowling was 30° C. The amount of air was of the order of 25 cu. ft. per second. The cylinder was run full throttle for 10 hours non-stop under those conditions. One could reasonably expect an engine to give fairly good service under those conditions, although, of course, if the temperature were increased the life between overhauls would naturally be shorter.

The CHAIRMAN: Where was the temperature of 250°?

Mr. TAYLOR: The hottest part of the cylinder head.

The CHAIRMAN: That is a very hot cylinder.

Mr. TAYLOR: It was normally a good cylinder, but he agreed that under the conditions of the test it would be regarded as a hot cylinder.

The CHAIRMAN: Does the speaker think that the average temperature over the whole cylinder would have been much above 200°?

Mr. TAYLOR: No. The heat loss from the cylinder, *i.e.*, the heat gained by the air, as measured agreed very closely with the figures he had obtained in his experiments at the R.A.E. on water-cooled engines; it was about 55 per cent. of the b.h.p.

ORAL REPLY TO DISCUSSION

He could not state off-hand what was the quantity of air that went through the engine. He would give the figures in a written communication.

Mr. TIZARD: He was a little doubtful as to whether the conditions in the wind channel tests were precisely parallel with conditions in flight—whether the sizes of the fuselage and everything else corresponded.

Mr. MCKINNON WOOD: That was so. The quantity of air that was found necessary in the first set of experiments was represented in the second set by a corresponding quantity of air going through the gauze. He believed the rise of temperature of the air was about 20°; but whatever it was, the effects of the rise in temperature had been brought into the results.

With the jacketed cylinder, as he had put it forward, it might be possible to deal with special hot spots in a manner in which they could not be dealt with when a cylinder was merely exposed to a blast of air. With the jacket, the air was conducted as desired and its velocity could be increased locally, so that its heat-extracting power was increased at the point at which the greatest heat occurred. We might so be able to design engines with the exhaust valves at the back, which might be convenient from the point of view of attaining good shape for low body drag.

The CHAIRMAN: Could other than tangential flow be arranged for?

Mr. MCKINNON WOOD: It might be difficult.

Aerodynamically, a cylinder with a close jacket around it was entirely different from a cylinder in a free stream of air. With bare cylinders there was big disturbance of the general flow. In his proposed arrangement, only the air necessary to take up the heat would be carried through, whereas in other forms of cowled engines there was a good deal of surplus air going through, and in its passage through the body it was giving rise to drag.

Dr. A. P. THURSTON: Had Mr. McKinnon Wood tried directing the air spirally around the cylinder?

Mr. MCKINNON WOOD: This meant a smaller flow of air and a bigger rise in its temperature. The cooling capacity of the air in the later parts of its journey would therefore be lower.

Dr. THURSTON: It must follow a perfectly streamlined path round the cylinder.

Mr. MCKINNON WOOD (*continuing*): With regard to the point that 30 per cent. of the power developed was expended in cooling an air-cooled engine, he said that that applied only to an aeroplane travelling as fast as it was possible to make an aeroplane travel by means of an uncowled air-cooled engine, and to

an air-cooled engine with the cylinders exposed. The effect of the Townend ring, according to the evidence he had been able to collect and analyse, was to halve the difference between the air-cooled aircraft and the water-cooled with honeycomb radiator of the best types now in use. He had had access to a good deal of evidence, and whilst it was difficult to analyse it and reach definite conclusions, the water-cooled-engine aircraft appeared definitely faster than the air-cooled-engine aircraft.

Dealing with Mr. Tizard's question as to whether the drag was much affected by the speed of entry and exit of the air, he said he did not think the speed at which the air entered the duct mattered very much, but the speed at which it left probably mattered quite a lot, and he imagined it was desirable that it should come out at something like the speed of flight.

The figures given by Major Green and Mr. Taylor seemed to fit in very well with his own. He had said before that there seemed very little definite information about the heat flow, and, in giving the measurement of 55 per cent. of the b.h.p. as the heat flow through the cylinder, they had given him the first definite measurement of that kind he had ever heard. It had seemed extraordinary that no one had ever measured the heat flow through the cylinders of an air-cooled engine. Such measurements had been made at the R.A.E. on water-cooled engines, and much the same figure was obtained.

Captain F. S. BARNWELL (*communicated*): It is unfortunate, academically, that the terms " air-cooled " and " water-cooled " are employed as descriptive of two types; because, of course, both types are air-cooled. However, if it be granted that " water-cooling " means that heat is conducted from the walls and head of the cylinder, by water, to a separate air-cooled radiating surface, one had better use the terms because this is current practice.

Referring to Mr. McKinnon Wood's figures for drag necessary for cooling. His company had during the last fourteen years done a large amount of wind-tunnel experiment on drag of engines and bodies, in the Bristol Aeroplane Co.'s wind-tunnel. The work has been confined mainly to finding out how, by adding various " cowlings," the drag of existing engine on existing bodies may be reduced. One is in agreement with Mr. McKinnon Wood that, at a speed of 180 miles per hour, the drag-horse-power due to an air-cooled engine may be as high as one third of the brake-horse-power; but this is the " worst " case of naked cylinder heads sticking out through the cowling, and further, of the cowling having both front and rear openings to afford " crankcase cooling." But, from their wind-tunnel experiments, run concurrently with actual flight tests, it would appear that one can " cowl " the modern air-cooled engine so that, at 180 miles per hour, the drag-horse-power due to cooling the engine adequately is only about 14 per cent. of the brake-horse-power.

One feels compelled to question Mr. McKinnon Wood's statement about fuel consumption. Is this necessarily higher for the air-cooled than for the water-cooled engine? Can the fact that the mean cylinder temperature of the air-cooled engine is higher than that of the water-cooled necessitate higher fuel consumption for the air-cooled? Personally, he could not see why this should be so.

One agrees with Mr. McKinnon Wood in that an engine-driven fan appears a sound scheme for ensuring adequate cooling at all flight speeds; but it seems doubtful whether cooling drag could be reduced by its use and it would absorb some part of the brake-horse-power. One feels therefore that one would only resort to it should it be impracticable to attain efficient cooling without it.

As regards the question of complete " air-jacketing," as a means of reducing drag whilst retaining adequate cooling. It is outside the scope of the present discussion to consider the practical difficulties of doing this, but obviously these would be very great particularly in view of accessibility. The primary argument in favour of " air-jacketing " is, of course, that drag-horse-power varies as the cube of the speed whilst cooling varies rather less than linearly as the speed;

hence, the slower the air speed the better should be the ratio between brake-horse-power and horse-power absorbed by cooling drag, provided always that it be possible to induce the air to absorb the necessary units of heat. A secondary argument is that, by suitable " jacketing," a non-turbulent exit air flow might be achieved.

But there is one point, respecting engine cooling in general, which should be considered at this stage:—In the normal aircraft engine the brake-horse-power represents about 28 per cent. of the heat energy given out in burning the fuel. Mr. McKinnon Wood quotes an amount equal to one half the b.h.p., or 14 per cent. of the fuel heat, as being dissipated by " direct " radiation from the cylinder head and walls. The rest of the heat, 58 per cent. of that given out by the fuel, must depart with the exhaust gases, be absorbed by the lubricating oil and be conducted to, and radiated from, the " rest " of the " outside " of the engine. He believed that the commonly accepted figure for the amount of heat carried away in the exhaust gases is 40 per cent. of the fuel heat; if one accepts this figure, it will be seen that 18 per cent. of the fuel heat (a slightly greater amount than that dissipated by " direct cooling ") must be dissipated by radiation from the " rest " of the engine and from the surfaces of additional oil coolers (should these be necessary). The point is therefore, that this relatively large amount of heat will be of much the same amount whether the engine be " air-cooled " or " water-cooled," and its dissipation will presumably cost the same in drag for both types.

The obvious advantage of " air-cooling " over " water-cooling " is " temperature difference;" the " temperature difference " for the " air-cooled " engine is about three times that for the " water-cooled." The obvious advantage of " water-cooling " is that the air-cooled heat dissipating surface may be made of low-drag form, whereas the finned cylinder (with valve-gear) of the normal " air-cooled " engine is of high-drag form and this is more or less necessitated for practical engineering reasons.

It would not appear, logically, that the disposition of the cylinder of an " air-cooled " engine should make any appreciable difference to the drag necessary for cooling. Given the same cylinder and valve gear, a certain minimum air speed past it, and hence a certain necessary cooling drag per cylinder, must be achieved; there seems no logical reason why either figure should be affected appreciably by the disposition of the cylinders.

This leads to what appears a very important consideration. It is one on which there is little information and one hopes that Mr. McKinnon Wood may be able to furnish some. Given a certain design of " air-cooled " cylinder and valve-gear and given that a certain " free " air-speed past this cylinder be found necessary for cooling, it might be argued that the necessary cooling drag (for this particular cylinder) is fixed and cannot be made lower. The use of some form of " cowling " or " jacketing " combined either with an engine-driven fan (or with suitable adjustable inlet and outlet openings for the cooling air), could ensure that the necessary air speed (no more and no less) past the cylinders was provided. The point on which one needs information is this:—with " cowling " or " jacketing " a certain minimum mass of air must be led past and around the cylinder to cool it; without " cowling " or " jacketing " a certain " free " air velocity past the cylinder is necessary to cool it. In both cases there will be drag due to cooling; for the latter case this drag can easily be determined. Is there proof that the drag for the former case can be much lower than for the latter, and if so by about how much?

One would expect that it might be, because with " cowling " or " jacketing," the air flow may cause a mean force on the " cowling " or " jacketing " inclined forwards and, again, the " cowling " or " jacketing " might considerably suppress turbulence; the " Townend ring " may be quoted in evidence.

The matter appears to be of extreme importance in its bearing on the future design of " air-cooled " engines, and he thought it could be summarised thus:—

Assume they had ·

(*a*) An engine with normal cylinders and valve gear fitted with complete " jacketing."

(*b*) An engine with low-drag form of " cylinders " also fitted with complete " jacketing."

With both engines developing the same power and adequately cooled by passing the correct amount of air, per unit time, through their respective " jacketings," would the drag of engine (*b*) be appreciably lower than that of (*a*) ?

In other words, by the best possible form of " jacketing," can the fact that the actual radiating surface is of " free-air " high drag form be rendered of comparatively minor importance?

Mr. A. NUTT (Vice-President, Wright Aeronautical Corporation, U.S.A.), (*communicated*) : In reading over Mr. Wood's paper he was very much in agreement with the general principle that far too much horse-power is being used to cool air-cooled engines. In this country the higher powered air-cooled engines are being put into flight service using a considerable number of baffle parts around the cylinders, thereby approaching the ideal condition of air-cooled jackets such as suggested in Mr. Wood's paper.

He did not agree with the statement that " all the cowling rings that have been devised increase the cylinder temperatures appreciably." As a matter of fact both the cowling and rings that have been used here have definitely decreased the temperatures and it would be impossible to run these engines in flight service satisfactorily unless both cowling and rings were used.

Regarding the use of so-called side valves behind the cylinders, while the top of the cylinder would be favoured the valve cooling would certainly be impossible. Furthermore, the combustion chamber problems are very great when using valves as large as are necessary for high outputs in aircraft engines.

There is one installation with which he was familiar that has made use of a small propeller attached to the flight propeller to provide a greater flow of air around the propeller hub. This installation was on a water-cooled engine with a nose radiator and the addition of the small propeller was necessary on account of the lack of blade area at the propeller hub on a large diameter slow moving propeller.

The use of a fan for cooling aircraft engines probably dates back to at least as far as 1914 when Mr. Caproni used this means of cooling a small air-cooled engine successfully. It is rather strange that this method of cooling has not received more attention during the past fifteen years.

The use of a completely cowled air-cooled engine would permit the use of shutters to control the temperature of the engine in sub-zero weather eliminating the rather dangerous procedure of bringing an airplane into a field in a power-stall in order to keep the engine warm.

The application of the results obtained in the tests reported in the paper should be very interesting.

Air-Commodore J. A. CHAMIER (*communicated*) : The Lecturer, in his appendix, described the channel through the body as a sort of venturi tube. As such it is plainly a bad venturi as it cannot conform to an ideal shape. Is there no increased flow possible by considering the passage merely as a tube to which suction is applied and exhausting into the throat of a really efficient venturi cowling? Possibly the drag of such a venturi would be excessive?

Mr. A. H. R. FEDDEN: He had listened with much interest to the series of instructive experiments described by Mr. McKinnon Wood on Engine Cooling Research, and his proposals for completely enclosing an air-cooled engine, and cooling by fan induction instead of flight induction, and gathered that he has

arrived at the already established practical conclusion that reduction in drag is generally incompatible with ease of cooling.

He agreed that a good deal may be accomplished to mitigate this problem and he thought that all builders of air-cooled engines will welcome research along these lines, but he did definitely join issue with him that the patient is in the desperate condition outlined in the opening remarks of his paper. With regard to the discussion of air-cooled versus water-cooled, he would ask Mr. McKinnon Wood if his drag figures have been taken for the air-cooled engine in conjunction with a bare and perfectly streamlined nacelle only, rather than with a completely equipped military aircraft. He suggested that had the latter case been considered the figures would have been far different. He suggested that Mr. McKinnon Wood is starting out with an incorrect assumption in comparing air-cooled aircraft of the past having *bare cylinders* with aircraft having air-cooled engines with *speeds* of the order of 200 miles an hour which are now obtained. Surely they must compare these latter installations with corresponding air-cooled ones of similar vintage. Without exception modern air-cooled aircraft of that type both in Europe and America employ ring cowlings and under these conditions he was not prepared to agree to the statement that from available data of performance tests the air-cooled engine is behind the water-cooled type with ring cowling.

Recent tests of identically the same types of aircraft, both single-seater, two-seaters with air-cooled and water-cooled power plants, have proved that with modern air-cooled cylinder design and suitable ring cowling the difference in speed has been not more than 1-2 per cent. and in most cases the climb of the air-cooled engine aircraft has been superior.

One of the most eminent authorities on engine design in America has recently stated that after exhaustive experiment it has been found that there is no appreciable difference between the performance of their latest fighting aircraft with either air or water-cooled engines, unless recourse is made to skin radiators as used in the Schneider Trophy races, and in support of this statement the fact was brought out that the United States Government have ordered for the current year engines of over 500 h.p. to the extent of 720—220 being of the liquid cooled type, the balance being air-cooled radials.

Still referring to the question of drag he would be interested to hear the author's views on the relative drag of the water-cooled engine with normal radiators (not wing surface type) and the air-cooled engine enclosed in a N.A.C.A. cowl, in view of the astounding speeds reached in the recent Cleveland Race Meeting last autumn, when speeds of 308 m.p.h. were attained and if he thinks these speeds could have been approached with water-cooled engines of similar swept volume.

He was surprised to hear that the greater weight of the water-cooled engine counterbalances the greater supply of fuel demanded by the air-cooled engine and he challenged the statement.

He would have thought that Mr. McKinnon Wood would have been familiar with recent experiments carried out at the R.A.E. on the fuel consumption of air-cooled engines which he submitted conclusively deals with this statement.

The question of fuel consumption on air-cooled engines is a hardy annual which dies hard and recent comparative official tests with installation using air-cooled and water-cooled engines have conclusively proved how closely the cruising consumptions of the two types of engines approximate. He thought this incorrect impression dated back to early cylinder design when conditions were very different to those met with in modern up-to-date design.

From the above remarks he did not want to suggest that the air-cooled engine maker has not many problems to solve. Turning to a constructive criticism of the paper, he entirely agreed that the engine maker should market his engine as a complete unit, and air-cooled radials both in Europe and America are now being

offered complete with ring cowling, exhaust system, oil cooler, air intake, etc., it only being necessary to couple up petrol and oil systems.

The introduction of ring cowling has necessitated a serious reconsideration of air-cooled cylinder design. The Bristol Company recently carried out some interesting tests of a full scale engine through the courtesy of the Vickers Company in their new large wind tunnel. These tests proved what they had suspected for some time, that an efficient ring cowling reduced the wind speed over the cylinders by about 40 per cent. Some figures on modern cylinder fin area may be interesting.

The " Jupiter " cylinder fin area is	1284	sq.	ins.
" Pegasus "	,,	,,	,,	2032	sq.	ins.
" Cyclone "	,,	,,	,,	2020	sq.	ins.

Written Reply

Several speakers have drawn attention to what I think is the most important conclusion which emerges from my paper, the importance of the regulation of the flow of air over the engine to give the same cooling approximately at all speeds of flight. I have considered doing this by the use of a fan chiefly, but I mentioned variable cowling, and Major Green also spoke on the latter. The fan is only essential if sufficient cooling cannot be obtained without it and it is not clear that this is so with the jacketed engine. I would suggest that a convenient form of variable cowling for existing engines would be a variable Townend ring of polygonal form composed of symmetrical aerofoils which could be set to lift inwards when climbing and outwards at top speed. This should give a higher velocity over the cylinders on the climb than would occur if the ring were removed. If such a ring could be controlled thermostatically a valuable development might result.

The enormous increase in cooling surface from the " Jupiter " to the " Pegasus " quoted by Mr. Fedden is of much interest. My fin area corresponds closely with the " Pegasus " and this suggests that, since the " Jupiter " is known to have been satisfactorily cooled by long experience, the arrangement I have discussed should give ample cooling when the velocity over the fins is equal to flight speed (plus slipstream).

I expected my temperature of 250° C. to be attacked. I am inclined to think the Chairman's figures are rather too cautious and Major Green appears to support me here. My paper does not, however, perhaps make it very clear that although I at first suggested 250°, the later and greater part of my discussion is based on a temperature of 200°. In discussing the fan-induced flow I took the velocity over the fins equal to the external velocity and this should give adequate cooling at 200°. 250° would correspond to a velocity over the fins of 3/4 of the external velocity. It has been my policy to keep a margin in hand in the argument in the paper, and I expect that experiments on a larger scale will yield more favourable results. In particular it is estimated that the efficiency of the fan will rise from the 65 per cent. of the model experiment to 90 per cent. full scale. This would reduce the value of D_v for model 7 from 3.3 to 2.65 on the climb, and from 1.5 to 1.4 at top speed.

My estimate that at 180 m.p.h. 1/3 of the horse-power would be consumed in cooling the engine in the case of totally exposed cylinders has been questioned, but Capt. Barnwell supports me here. The figure is based on a complete small aircraft, but with a very much exposed engine, and I know that the drag can be appreciably reduced by partial fairing, still leaving the cylinder heads exposed. There is a consistency between the two estimates we have been given by Mr. North and Capt. Barnwell for the corresponding figure with a Townend ring and, taken in conjunction with my figure for the fully exposed cylinders, their figures suggest that the Townend ring would add 4-5 per cent. to top speed, which figure I accept, and I suggest that we are all in good agreement. The Townend ring (with

engines of sufficient fin area) has made a great advance in reducing 30 per cent. to 15 per cent. The object of my paper is to discuss what further reduction can be made and my hope is to see it reduced to 5 per cent.

The question of in-line engines was raised. I have hardly any data to answer this question. It seems possible that the drag would be less, but I also feel certain that the cooling could not be obtained by simply exposing the cylinders. All such engines have had some form of cowling.

I agree that there is no inherent reason why the consumption of an air-cooled engine should be greater than that of a water-cooled engine, except at full power, when a strong mixture appears to be necessary with air-cooling. It would have been more reasonable to have based my statement on a throttled consumption and then the air-cooled engine will have the advantage of lower weight.

In answer to Mr. Pye and Mr. Tizard, the model experiments with the fan were based on the idea of a 1/5 scale representation of a body containing an engine of 560 b.h.p., requiring a heat flow through the cylinders of 280 h.p., and having a duct area of 1.9 sq. ft. The quantity of air required for cooling would be 375 cu. ft./sec. (2/3 of a cubic foot per h.p.) for a cylinder temperature of 200° C. and 280 cu. ft./sec. (1/2 cu. ft. per h.p.) for 250°.

In reply to Air Commodore Chamier, the flow through the engine could undoubtedly be much increased by exhausting into the throat of a venturi cowling, but, also without doubt, the drag would be much increased.

I think Capt. Barnwell underestimates the heat carried away by the exhaust, which is, I believe, 50 to 55 per cent. of the fuel content. I should also put the b.h.p. a little higher and little residue would then be left. The oil cooler only conveys about 1 per cent.; any heat flow from the body surface is irrelevant to the discussion, as it causes no drag. Strictly, any heat conveyed by air flow over crankcase or oil cooler should be dealt with through a fan or variable cowling system; but the amount may not be large enough to make this of much importance.

As to his final question, I would urge again that a jacketed engine has no aerodynamic relationship to an engine with exposed cylinders, or to an engine in a ring. I think that there would be little difference between (*a*) and (*b*) when jacketed and inside a body, if the low drag of (*b*) were due to the general shape of the cylinders (*e.g.*, oval cylinders), but that if it were due to finer detail which would make the passages of the jacketed engine of less resistance, then (*b*) would have less drag when jacketed.

Referring to his final paragraph, and in answer to points raised by other speakers, when the flow breaks away from the sides of a body, I expect jacketing to increase the cooling and reduce the drag by retaining the flow along the body surface. We have in fact experimented with a plain cylinder with jackets giving passages of width 0.1 and 0.05 of its diameter. The virtual drag coefficient of the cylinder was found to be roughly 0.06, or about one eighth of the free air drag. By virtual drag I mean the force by which the mean air speed is to be multiplied to find the rate of consumption of energy and this includes the drag of the jacketing walls. I give this as an example of the principle only; the drag of a finned cylinder would be much less reduced and, in fact, the virtual drag of the finned cylinder in the first series of experiments of my paper is of the order of 0.25 on barrel diameter.

The 563rd Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

Eighth Meeting, Second Half, 68th Session

The Eighth Meeting of the Second Half of the 68th Session of the Royal Aeronautical Society was held in the Lecture Hall of the Institution of Civil Engineers on Thursday, April 6th, 1933. In the Chair, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President of the Society.

The President: He felt bound to make some remarks about the terrible disaster that had befallen the United States Airship "Akron," with its consequential loss of the lives of over seventy gallant men. That disaster inevitably brought to their minds their own recent loss of the "R.101" and the Anglo-American disaster to the "R.38" some eleven years ago.

The audience would remember that only a few months ago the "Akron" was described to members of the Royal Aeronautical Society by Squadron-Leader Booth. They would also remember the unstinted admiration which was expressed for that bold project, and the high hopes that were based upon its prospects; and that those high hopes should have ended thus, is a tragic, but not, unfortunately, a novel experience in the story of the conquest of the air. Unfortunately, those disasters afforded recurrent opportunities for defeatism to raise its head, and it is now being suggested that the struggle should be abandoned and the development of the airship given up. Such, however, was not the lesson of history; still less was it their contemporary experience. Mankind did not turn back when once its face was set on the path of scientific progress. On the contrary, one could feel the greatest admiration for the indomitable courage, for the incredible tenacity of purpose, of those concerned, and particularly those concerned in airship development. Disasters might delay, but they could not prevent the final triumph of mankind over the elements, and possibly some day the defeatists would realise that their criticisms were of no help in the struggle or of any comfort in reverse. He felt sure that he was speaking for everyone present in expressing to the people of the United States, and in particular to the bereaved relatives of those gallant men, their profound condolence with them in that tragic happening, and their sincerest sympathy.

Turning to the question of that evening's Lecture, unfortunately he had to announce that, owing to totally unexpected pressure of business and other events, Dr. Dornier was unable to appear himself; but he had very kindly sent a very worthy representative in the person of Herr Schuettel, his Assistant Engineer, who would read Dr. Dornier's paper and would be prepared, as far as possible, to answer all queries which might be raised on it.

He (the speaker) drew attention to the fact that a few years ago Dr. Dornier made his first public announcement of the design of the "Do.X" before that Society, and it would be very interesting to compare the estimates then with the story of the result as it would be told by Herr Schuettel, and they would be able to see how closely the estimates had been realised. In 1928 Dr. Dornier estimated that his total all-up weight would be 118,800lbs., and Herr Schuettel would tell them that they realised and carried a weight of just over 123,000lbs. He (the

speaker) did not know whether any copies of the original paper were in existence, but he had no doubt that the Secretary would be able to turn some up if anybody required them.

LESSONS OF THE Do.X

BY

DR. C. DORNIER

It gives me particular pleasure to accede to the request of the Royal Aeronautical Society and to tell you the conclusions I have reached with regard to the flying ship Do.X. It was with great regret that I was compelled to ask you to postpone my lecture, but I trust that the subject is nevertheless still of a certain amount of interest to you.

In the spring of 1928 I had the honour to lecture on the subject of a family of flying boats and on that occasion, for the first time, I made public details of the flying ship then under construction and which eventually became the well-known flying ship Do.X.

The data which I then gave led to what was, for me, an unforgettable discussion, in the course of which naturally many doubts were expressed as to the possibility of translating them into practice and the possibility of obtaining in practice the calculated performances.

Doubt was expressed in several quarters whether the suggested aircraft would succeed even in rising into the air and in the improbable event of that happening it was feared that an enormously long " take off " and " landing " run would be required

Much doubt was also expressed as to the ship's flying characteristics, it was feared that the stability in the air would prove insufficient. It was pointed out that if the aircraft should actually rise into the air it would only do so as the result of non-adherence to the regulations for aircraft structures in the matter of factors of safety.

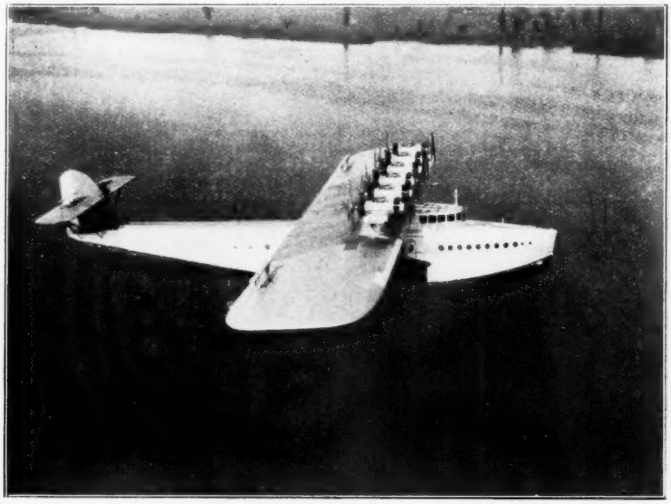


FIG. 1.

As regards the pilot of such a boat it was, as far as I can recollect, remarked that in order to operate the number of levers and instruments necessary for 12 engines he would require to have the manual dexterity of a Paderewski. It was particularly doubted whether with such a large boat it would be possible to obtain a reasonable ratio between unladen weight and useful load.

I have taken the liberty of referring to this discussion, which took place five years ago, as it occurred in circles whose competence cannot be denied in questions of this nature. The fact that such serious doubts were then expressed goes to show the technical position at that time. It also goes to prove the difficulties which stood in the way of undertaking the construction of a flying boat of that size. The difficulties were not only on the technical and material side but arose to a large extent, I would like to say, from the nearly unanimous rejection of the idea of flying ships by the technical world. To-day everyone knows that flying boats of the size and weight which I then described in your company for the first time, can " take off," fly and land, and that the pilots need not be specially trained artists. Indeed one has now very nearly forgotten that it is only a few years since the idea of a flying ship was looked upon as Utopian. But when to-day the flying ship is acknowledged to be a *fait accompli* and all manner of projects for flying boats are evolved compared with which our Do.X is as a gnat to an elephant, technical circles are nevertheless still far from acknowledging the flying ship to be either a necessary or a useful instrument worthy of further development.

Opinions to-day as to the importance of flying ships are very divided and if what I am about to say should contribute towards clarifying the position, I should count it as an achievement.

Those among you who specialise in the construction of flying boats may know of my lecture on " The Flying Ship " which I gave before the German Aeronautical Scientific Society, the Wissenschaftliche Gesellschaft für Luftfahrt, in 1929 in Berlin, at which I outlined the constructional details of the first flying ship, and also another lecture which I gave in 1931 at the Technical High School, Munich, on the subject of " Flying Boats," and some of you had the

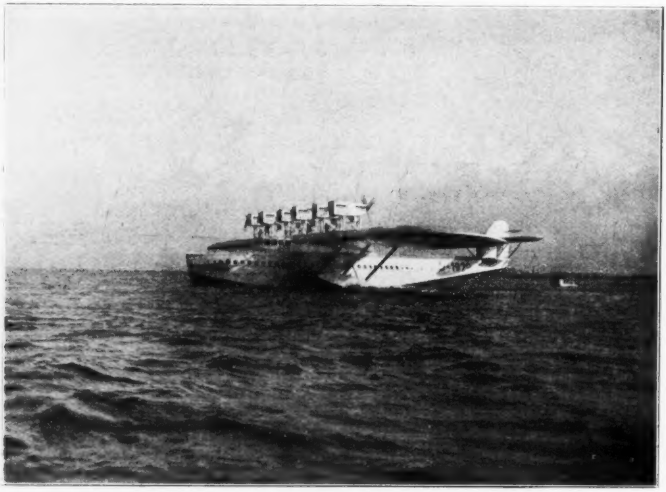


FIG. 2.

opportunity of inspecting the Do.X in Friedrichshafen and also at Calshot. There we had the honour, not only of greeting His Royal Highness The Prince of Wales on board, but also the pleasure of his piloting the ship.

I can, therefore, refrain from describing details of the construction and will only touch upon such as have either proved their worth or have shown that they required modification.

The subject matter of this lecture will cover three different examples of the flying ship: the original Do.X 1 aircraft fitted with air-cooled engines (Fig. 1) which, in my previous lecture, was marked " E." After its acceptance, this boat was fitted with water-cooled engines and I shall refer to it in this form in future as Do.X 1a (Fig. 2).

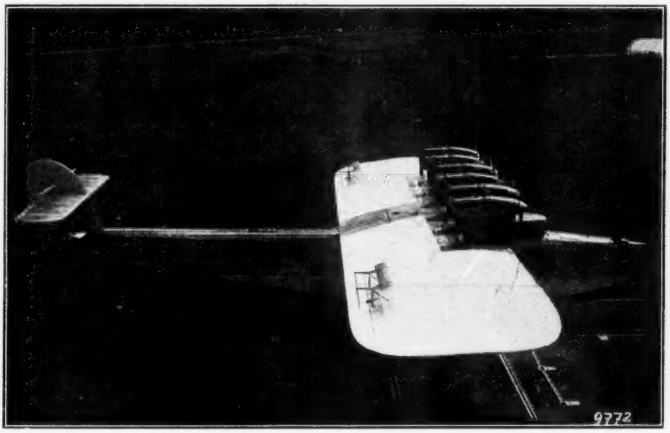


FIG. 3.

The third type, of which two examples have been built to the order of an Italian group, will be referred to as Do.X 2 (Fig. 3).

The preliminary work on the first flying ship was begun in the year 1924. A large number of designs were produced and the number of engines with which they were to be fitted ranged between seven and twelve. All designs, however, incorporated one central hull and a single wing. During the design period a large number of mock-ups were constructed and a mock-up of the eventual design was built to full scale with every instrument, lever, and fitting installed (see Fig. 4).

This system of using mock-ups for all details proved so extraordinarily useful that we now build no new aircraft without first constructing it in wood and cardboard to full size and with all equipment.

The guiding principle throughout the design period was only to make use of such features as had been proved technically sound. All experimenting was avoided if it was possible to do so. It is clear that owing to this policy original and creative design was handicapped to a certain extent. The fact, however, that from the time that tests started to the ship's acceptance, only a total of a few hundred working hours were required for alterations to the aircraft, proves the correctness of the adopted system.

In the summer of 1926 the general layout was finally dcided upon. In December, 1926, design was started. One year later construction was begun in the works at Altenrhein. The launching, together with the first flight, took place on the 12th July, 1929. The Do.X 1 was taken over on the 20th February, 1930.

The tests carried out in the autumn and winter of 1930 showed that the air-cooled engines were not able to develop the 400 h.p. continuously, which our calculations required.

The guaranteed contract performances regarding useful load, speed and " take off " were unquestionably obtained, but we were compelled sometimes to fly at engine revolutions which, as it very soon proved, were too high for this particular type of engine. This was a very hard blow to us. The reduction of the actually available cruising horse-power had so altered the whole performance of the flying ship as to preclude the possibility of her achieving the purpose for which she had been built. In the spring of 1930, therefore, we had to decide either to instal engines of sufficient normal power, say, of 420 h.p., in order to prove the usefulness of flying boats in practice, or to bury all thoughts of vindicating this new method of transport for a good many years.

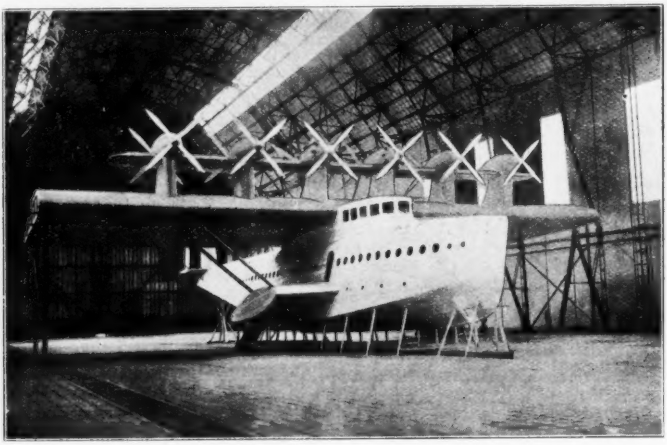


FIG. 4.

The choice of air-cooled engines was made in order to keep down the weight of the ship as compared with water-cooled engines. In choosing air-cooled engines, however, the mistake had been made, owing to lack of experience, of overlooking the ratio between cruising horse-power and full power, and conclusions were thus drawn adverse to water-cooled engines.

As more powerful air-cooled engines were not available, and as, in addition, serious trouble had developed through the insufficient and irregular cylinder cooling of the aft engines, it was eventually decided to instal water-cooled engines. The increase in weight resulting from the change was proved in subsequent tests to have been more than compensated for by the higher cruising horse-power available. Curtiss Wright Conqueror engines with a reduction gear of 2 to 1 were fitted. The maximum power of these engines is 615 h.p., developed at 2,450 revolutions, and the guaranteed cruising horse-power is 415 at 2,150 revolutions. Unfortunately, during the installation of the new engines we were obliged to sanction a number of compromises in the interest of economy both of time and of money. For instance the mountings for the new engines had to be made to fit the attachments for the old engine mountings, and this made it impossible to increase the diameter of the airscrews—although that was most desirable in view of the increase in efficiency that would have resulted. In order to save as much time as possible we refrained from streamlining the engine nacelle

supports and had to content ourselves with ordinary strut construction. Also the arrangement of the radiators differed radically from what we would have liked. On the ground of economy old radiators that we happened to have were fitted, and these, as it happened, proved reasonably suitable under all kinds of climatic conditions and also during long periods of taxying. From the point of view of obtaining the highest possible speed, however, their design and position left much to be desired. The engine mountings and radiators of the Do.X 1a are shown in Fig. 5.

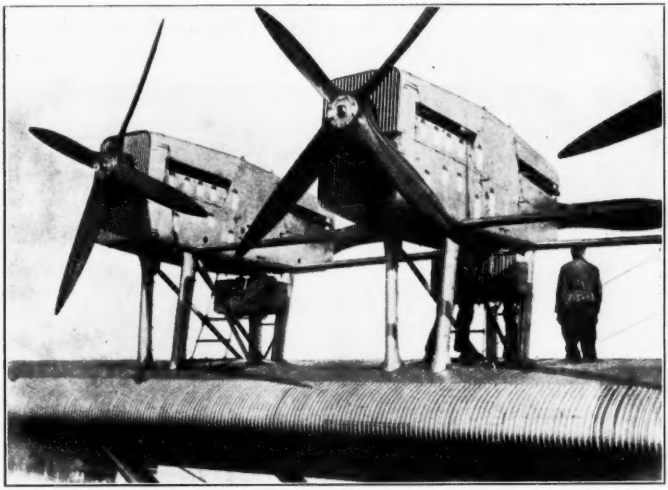


FIG. 5.

In the course of tests of the Do.X 1a it became evident that the omission of the streamline casing from the engine supports considerably reduced the accessibility of the engines in flight. For this reason, in the subsequent new version, the type Do.X 2, enclosed access to the engines was reintroduced, and this shaft served the dual purpose of housing the radiators. A further improvement in the Do.X 2 resulted from the oil coolers, which on the Do.X. 1a had been attached to the outside of the cowling, being combined with the water radiators. Fig. 6 shows details of the engine mountings of Do.X 2.

In Table I comparative figures are given of the weight of the power plant of the three different types. On the basis of the cruising horse-power available, the air-cooled design gives a weight of 1,885 kg. per horse-power, the American engines a weight of 1,624 kg. per horse-power, and the Italian engines a weight of 1,620 kg. per horse-power.

The change over to water-cooled engines in the Do.X 1 took place in the spring of 1930 and in August of the same year the first flight was made.

After three months tests on the Bodensee the Do.X 1a began her long distance test flights, about which you have no doubt already heard and which included two crossings of the Atlantic. This new departure from the accepted practice in aircraft tests aroused considerable and widespread criticism. But I am convinced that, as conditions were, there was no other way of collecting the variety of information we required and at the same time of demonstrating the possibility of the flying ship idea. I must admit that I seriously underestimated one factor, namely, the importance of the crew becoming

thoroughly accustomed to the ship. We had chosen our best people, but at the beginning both officers and crew were insufficiently " au fait " with this new instrument; the feeling of responsibility for the safety of this large boat may also have reacted on the judgment of the officers. It thus came about and was duly observed that at the beginning of the cruise the progress of the flight was extraordinarily slow. To-day, when one considers the flight as a whole, it is easy to see how familiarity and increased trust in the ship on the part of its crew was reflected in an increased rate of progress. The flights were never intended to set up records; at the same time it is interesting to note that a full three weeks were required from Altenrhein to Lisbon, whereas approximately the same time was required from Rio to New York and whereas the trip from New York to Berlin took five days.

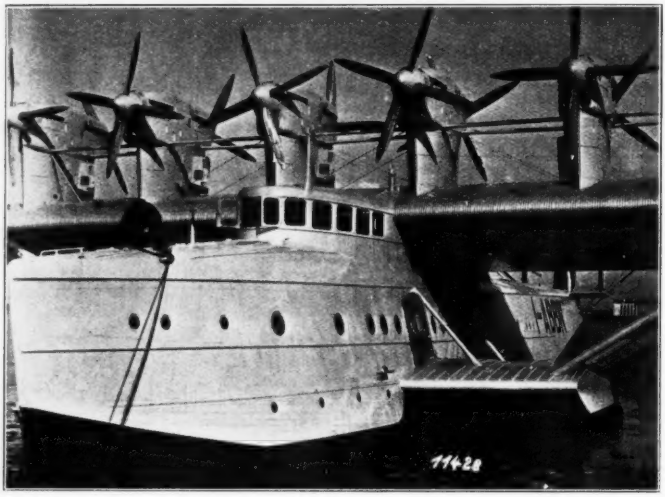


FIG. 6.

TABLE I.

WEIGHT OF ENGINE INSTALLATIONS.

Section: Power Plant.	Do.X 1 with 12 Siemens Jupiter Engines (geared).	Do.X 1 with 12 Curtiss Conqueror Engines (geared).	Do.X 2 with 12 Fiat A22 Engines (geared).
Engines with exhausts, fuel pumps and fittings, carburettor preheating, air intake for carburettor, oil radiator and the minimum permissible quantities of engine lubricating oil	5461	5219	6237
Radiator Installation complete with water, air scoop in the case of air-cooled engines	74	1691	2394
Engine starting gear	146	169	148
Engine controls	224	208	249
Airscrews with bosses	1102	796	1075
Total weight in kilogrammes	7007	8083	10103
Difference in weight compared with air-cooled engine installation		+1076	+3096
Permissible normal revolutions	1700	2150	1950
Permissible normal cruising horse-power	310	415	520
Permissible maximum revolutions	2100	2450	2100
Permissible maximum horse-power	500	610	630
Weight of power plant per horse-power at cruising output ...	1.885	1.624	1.620
Weight of power plant per horse-power at maximum output	1.168	1.105	1.337

The flying ship, Do.X 1a, took off from Altenrhein on the 5th November, 1930, for its great flight—the main routes of which are shown in Fig. 7—and returned to the works on the 15th November, 1932. During these 740 days the ship was continually in the open. One is entitled to assume that on such a flight, which extended over two years and during which time 65 different ports in three different continents were visited, the flying ship must have got into difficult situations and bad weather. The fact that the Do.X 1a actually only required minor overhaul work on its return to Altenrhein provides definite evidence as to the serviceability of the flying ship.

In any case, by adopting this form of test flight, we have gained a great deal of experience which would otherwise have taken very much longer to obtain.

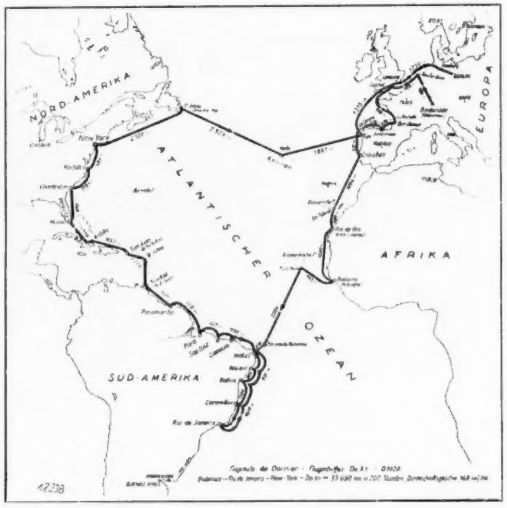


FIG. 7.

I would now like to say something about our experiences, both those of a satisfactory nature as well as those that were the opposite.

Power Units

During the whole of the test cruise no flight which was actually started had to be curtailed through failure of the power units. No trouble arose through the multiplicity of the engines. The number of engines, on the contrary, considerably increased the crew's feeling of security in the ship. The practice was gradually developed, when an engine was not running smoothly, of throttling it down and not taking much notice of it. The engines were always started within a reasonable time, which varied between three minutes and a quarter of an hour. But the mechanics suffered, especially in the tropics, owing to the necessity of starting the engines by hand.

The arrangement of the engines proved excellent for manœuvrability. A certain technique in manœuvring was developed, in that all engines were switched off with the exception of the extreme outside starboard and port engines and by alternatively using the throttles it was found possible to control the ship admirably.

If I were asked whether I would, in future, be afraid to use 12 engines again in a new design my answer would be that I should have no hesitation in doing so. One thing, however, is certain and that is that the use of larger power units arranged inside the wing would lead to substantial aerodynamical advantages. We have, for instance, found that by doing away with the engine nacelles and their supports an increase of nearly 50 km. per hour will result—equivalent to an increased operational radius of 25 per cent.

This gain, however, has certain disadvantages. For instance, the present arrangement of engines and airscrews above the plane has proved ideal for manœuvring the flying boat on the water. All overhauls of the engines, radiators and airscrews can, in addition, be carried out quite easily while the boat is on the water. The wing is, so to speak, the platform from which everything is easily accessible. The airscrews are out of the way of the spray and cannot be damaged in collision. This is borne out by the fact that every airscrew completed the two years' flight without defect and all are to-day absolutely fit for service. Going alongside, heaving a line, disembarking and embarking can be done without thought for the airscrews. But as soon as larger power units are available the airscrew diameter will become so large that a lot of difficulties will be unavoidable with this arrangement of the engines. Supervision of the engines was carried out, in the main, from the so-called " switch room " in which two men were continually on duty. During the flight it was usual for one mechanic to stand by for each pair of engines so as to be available immediately in the event of a breakdown. The pilots of the ship are, as is well known, not responsible for the supervision of the engines. At first this gave rise to all manner of qualms as our pilots were accustomed to well-equipped instrument boards and were unable to adjust themselves at once to the new conditions. However, they soon became accustomed to it and for my part there is no doubt that in future the pilots of large aircraft will always be relieved of the responsibility for supervising the engines.

Fuel Installation

The fuel is stored in cylindrical containers situated in the bottom of the hull. This arrangement has, without exception, been adhered to for more than 15 years in our large boats. The containers are made of duralumin and each has a maximum capacity of 3,000 litres. The total fuel carried by Do.X 1a was approximately 26,000 litres. The containers are connected to a petrol exchange from which petrol is pumped to two small tanks in the leading edge of the wing. To ensure as far as possible against a failure of the petrol supply three alternative systems were available, a wind driven pump, an electrically driven pump and a hand operated semi-rotary pump. From the wing tanks the petrol was delivered to the carburettors by means of " AM " pumps and any excess of petrol flowed back to the petrol sump. The whole of the petrol system is easily accessible in the air and gave practically no trouble during the whole flight.

The storage of petrol in the hull differs radically from the customary method in England of storing it in the wings. I decided upon the former system out of deference to the idea that petrol should be stored as far away as possible from the engines and all kinds of electrical equipment. The desire to lower the centre of gravity as much as possible, also played its part in that decision, a factor of less importance to English designers who employ auxiliary floats than to us who use stub wings. I am firmly convinced that the ship would have been a total loss through the fire in the wing at Lisbon at a time when she contained 20,000 litres of petrol, if the fuel had been stored in the wings; in fact any approach to the burning flying boat would in that case hardly have been attempted. At Lisbon the Captain filled that portion of the ship which contained

the tanks with fire extinguishing gas and the watch on duty were enabled to prevent the fire spreading to the leading edge tanks and to the engine nacelles by means of fire extinguishers.

The tanks and their mountings remained sound even after taking off in high seas with a heavily loaded boat, and no leaking whatsoever was experienced.

The system of storing petrol is capable, in my opinion, of substantial improvement and simplification if one is prepared to depart from the idea of special tanks and so constructs the bottom of the boat that the fuel is carried in a form of double hull.

According to our calculations, this method would, in a boat the size of the Do.X, save at least 500 kg. in weight.

This arrangement would have the further advantage of allowing the petrol to be protected from catching fire by means of a non-inflammable gas.

The Do.X was not fitted with dump valves which are strongly favoured by customers at present. I question whether such gear is really required on a boat with 12 separate power units.

FIG. 8.

Tanking

When one considers that during the Do.X 1a test flights approximately 400,000 litres of petrol were taken in it is obvious that the work of refuelling a flying ship is a very important business. By means of refuelling pipe lines permanently built in to the boat and a semi-rotary pump, which was always carried and which used to be placed on the stub wings, it was possible to take in up to 6,000 litres of petrol per hour. Fig. 8 shows how the refuelling normally took place.

The Hull

The first trial flights proved that the underwater shape of the hull was highly satisfactory. The boat had no wrong tendency, neither to get sucked down in the rear nor to bury its nose. The directional stability during take-off is very good and it is not necessary to assist the take-off by elevator movements.

Due to the change over from air-cooled engines to the water-cooled Curtiss Conquerors a small increase in the width of the stub wing was required in order to ensure the necessary stability, in view of the higher centre of gravity. This is the only external alteration to the hull of the boat that appeared necessary and has actually been made.

The hull strength was calculated in accordance with the existing German regulations of the German Aeronautical Experimental Establishment, the Deutsche Versuchsanstalt für Luftfahrt, and it is approved for an all up weight of 56 tons for freight traffic purposes.

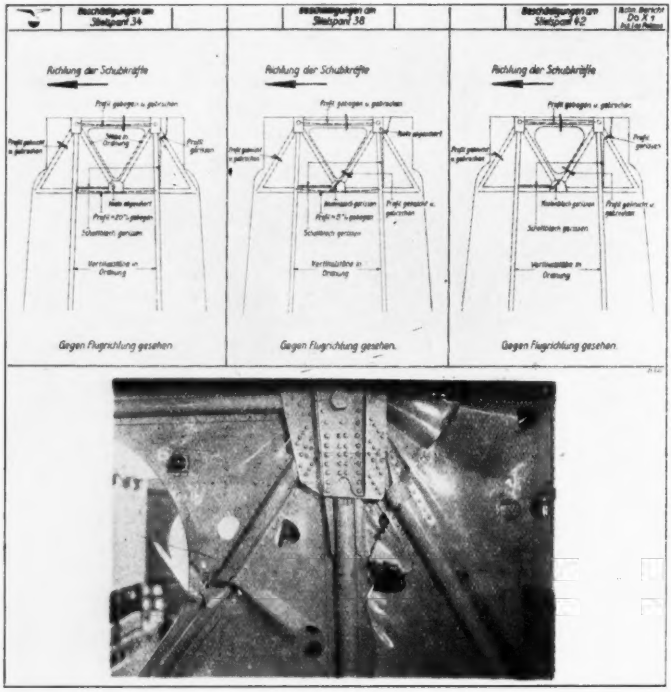


FIG. 9.

Certain strengthening was necessary as the result of damage which the boat sustained at Las Palmas. During an attempted take off under heavy load its starboard stub wing struck a high wave at a speed of 130 km. per hour.

This sudden braking action on one side introduced a twisting movement which caused asymmetrical inertia forces to turn the wing round its vertical axis in relation to the hull. The damage to the upper portion of the three main frames, on which the wing is carried, can be seen in Fig. 9.

The same degree of damage occurred to the top portion of all three main frames and was quite uniform. There had, up to that time, been no reason to anticipate such forces, and that experience supplied us with new knowledge of which we have taken due note. The hull and the stub wing remained absolutely watertight after the accident.

A certain amount of buckling and local denting of the starboard stub wing

took place, such as occurs very often in overloaded aircraft when taking off or landing in seaway.

Careful examination of the damage to the separate members of the supports enabled us, with the help of buckling and tensile tests, to come to some very interesting conclusions as to the magnitude of forces that had occurred.

The additional strengthening which was carried out increased the total weight by about 80 kg. Apart from this, only very slight alterations were required to the whole of the hull.

As the result of our experience to date, we are convinced that certain parts of the hull as originally designed are considerably over-dimensioned. For this reason we believe it possible in future, purely by a redistribution of material without increasing the weight, substantially to strengthen the whole of the hull.

FIG. 10.

The take-off and landing speeds of the ships so far constructed by us, which possess no slots or other means of decreasing the take-off and landing speed, are high on account of the high wing loading. These speeds are for a total weight of 55 tons in the region of 130 km. In spite of this, apart from the damage at Las Palmas, no defects in the hull developed during the whole cruise of the Do.X 1a, and we consider ourselves justified in thinking that with the existing wing loading, but using slots or flaps, a considerable increase in the seaworthiness can certainly be obtained.

If in future we store the petrol in a double bottom, as I have already suggested, instead of storing it in separate containers, the seaworthiness of the boat would be further improved. The skin of the hull itself would then absorb a large proportion of those stresses which arise when taking off and landing, and the framework of the boat would no longer be required to cope with them. As the weight of the fuel can account for as much as 30 per cent. of the total weight, it is quite clear that a substantial improvement in seaworthiness can be achieved on these lines.

It is interesting to note that the boat can take off in a side wind parallel to the swell. This starting technique came to be used more and more during the test cruise and without doubt frequently made take-offs possible which might have been disastrous when done across the swell. The demands as regards

taking off and manœuvrability made on the boat can best be shown by the places which were visited during the flights in Germany—these are shown in Fig. 10.

Of particular note was the visit to Hamburg, where take-offs and landings were made in the Parkhafen and on the Alster. The landings on, and flights from, the Müggelsee near Berlin were also a novelty.

The division of the boat into three different decks proved its worth, and will always be adhered to in future. Improvements, however, appear desirable in the sound-proofing of the passengers' cabin. The use, particularly in the tropics, of Cellon windows proved absolutely impracticable. We were compelled to substitute glass.

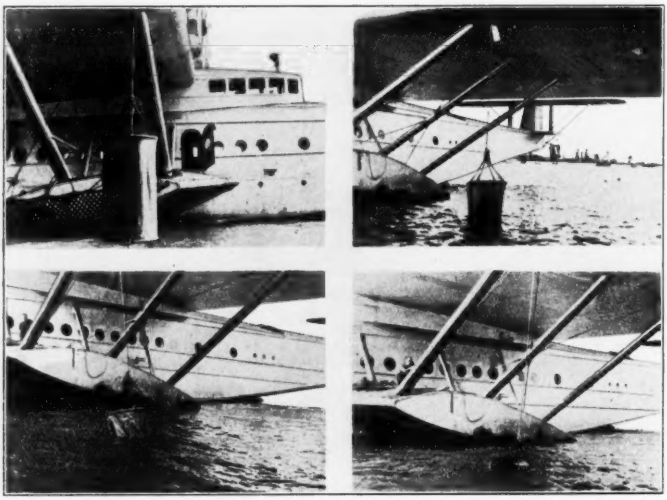


FIG. 11.

The relative arrangement of pilot's cockpit, chart room, and engine control room, proved most satisfactory and will be adopted in future construction. It became evident, on the other hand, that the wireless telegraphy cabin, which in the Do.X 1a is placed behind the engine control room, should be situated next to the chart room to assure better communication.

The stub wings, the underwater junction of which with the hull are well faired-in in contrast to our former practice, proved their worth thoroughly under the most varied conditions. They are quite invaluable for getting on board and leaving the ship, and for all manner of other purposes afloat. They make coming alongside in other craft a simple and safe operation even in rough weather. Furthermore, it was possible to take passengers and goods on board whilst taxying up to a speed of 30 km. per hour.

I am convinced that it was due to the stub wing construction that the accident at Las Palmas ended as well as it did. Had independent auxiliary floats been fitted the turning force would have been applied further away from the centre of gravity; that is, the speed of the turn would have been greater, so that, apart from the fact that the auxiliary float would have been crushed, a yet greater strain would have been placed on the wing supports.

The stability of the boat was fully tested—often under most difficult circumstances—and when correctly handled was amply sufficient. The behaviour of

the boat in tow and at a buoy is excellent. It frequently happened that the flying ship was moored to a buoy for many hours in a wind speed of 80-100 km./h.

We were the first to use trimming buckets as a precautionary measure whilst the Do.X 1a was moored to a buoy during changing squally winds, and obtained good results with them. These, which are shown in Fig. 11, consist of cylinder-shaped canvas containers fastened by a rope to the upper end of the wing strut; they are let down so far that they fill and are suspended so that their tops are level with the surface of the water. As soon as a strong gust of wind lifts the wing, the trimming bucket on the opposite end lifts, and for every inch it rises the weight increases. The same effect takes place whichever side rises. Their damping effect is excellent; and they gave very good service at Lisbon, for

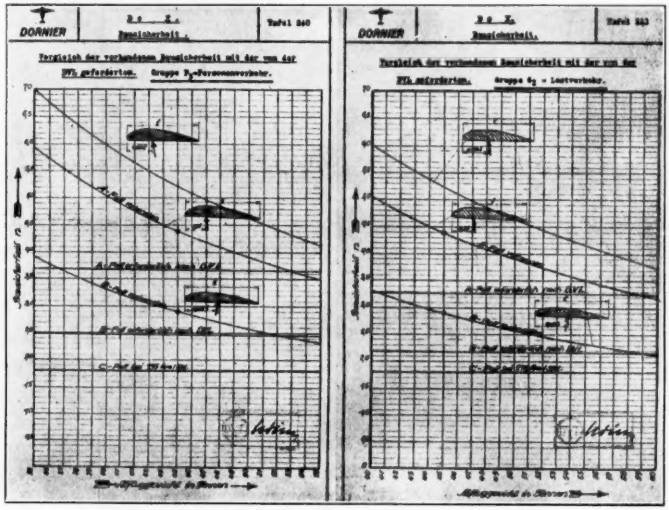


FIG. 12.

example, during repairs to the wing, where they were continually in use. As a result of this experience with the Do.X 1a we have recently fitted out smaller boats with this useful adjunct.

The wing is, as is well known, supported by struts extending from the stub planes. This method of wing fixture is often criticised unfavourably in expert circles. It was feared that damage to the stub plane in swells could endanger the entire wing structure. I can testify that, although we have adopted this type of wing bracing over a period of approximately 14 years in a great number of our boats, not one single case of stub wing damage led to an accident on the wing.

The system of supporting the wing from the stub plane has also proved itself satisfactory in every way in the case of the Do.X.

Wing Unit

The shape of the wing, its section, and its internal structure, have remained the same in all the three boats so far constructed. The assumed load factors, upon which the construction of the wing unit was based, are shown in Fig. 12.

For Group P3, passenger traffic, a gross weight of 52 tons is approved by the German Experimental Establishment, the Deutsche Versuchsanstalt für Luftfahrt. For goods traffic—Group G2—the boat at 56 tons fulfils present requirements.

As Do.X 1a did not weigh more than 56 tons during its flight from New York to Berlin, it is perhaps the first time that the Atlantic has been crossed by an aircraft that complied with the official regulations about load factors.

In passing, I should like to mention that this was the first Atlantic crossing of a flying boat carrying complete accommodation for 75 persons—a total weight of some 1,800 kg.

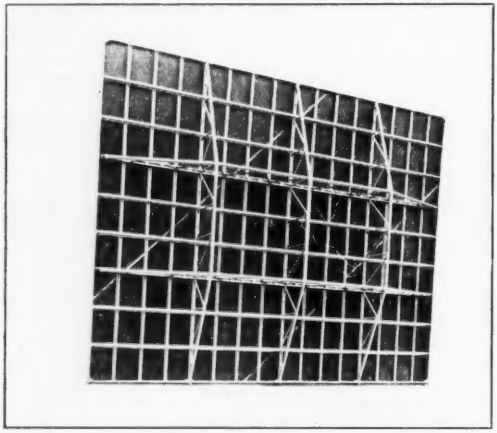


FIG. 13.

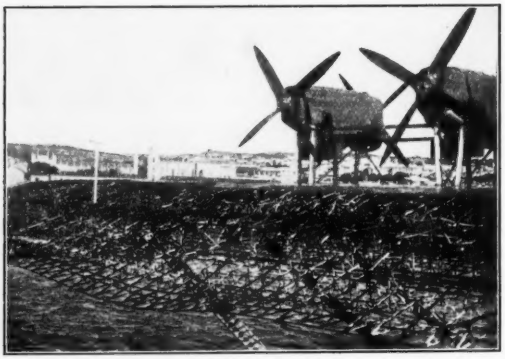


FIG. 14.

The wing itself is of three-spar construction and its surface is made up of rigid panels measuring 2.8 by 2.8 metres covered with thin metal sheet or fabric. In Fig. 13 a specimen is shown. This new system of wing covering proved its manifold advantages during the fire, which I have already mentioned, at Lisbon. The resulting damage to the wing caused by the fire can be seen from Fig. 14.

It was thanks solely to the interchangeability of the wing panels that we were able to carry out repairs without any extra help in so short a space of time—in the open and while the boat was in the water.

Fig. 15 shows the wing structure after the burnt parts had been removed.

In the following, Fig. 16, you will see the spare parts ready for transit to Lisbon. The complete repair was carried out within four weeks.

No signs of corrosion made their appearance in the wing.

The fabric covering of the wing proved quite satisfactory, in spite of considerable condensation having occurred internally at first. This undesirable feature was cured by sufficient ventilation.

The tail unit was calculated with particularly generous factors of safety, and even to-day falls within the most recent strength requirements. No alterations of any sort or strengthening of the tail unit have been found necessary.

FIG. 15.

It was decided to remain in New York for the winter as the season was too advanced for the return flight; a primitive slipway was made and the boat, chocked up, made its winter quarters in the Glen Curtiss Air Port. During this time she was struck by lightning, without being damaged, in the course of a violent thunderstorm. The involuntary delay was used for overhauling the engines completely and for carrying out some modifications suggested by the Curtiss Wright Corporation—the result of which increased the output of each individual engine by 50 h.p.

The excellent condition of the flying ship, after its return to Germany, can best be judged by the fact that, immediately after its inspection by the public, near Berlin, a flight round Germany was begun.

During the flight, Travemünde was visited and the opportunity was taken to put the boat into the floating dock which existed there—shown in Fig. 17.

On the return to Altenrhein the engines were taken out and inspected and only showed signs of insignificant wear.

The ship was again inspected minutely and put in order for the coming flights. The work involved was about 10,000 man hours.

The major part of the overhaul work consisted of renewing the wing fabric which we considered advisable.

Flying Performance

The largest weight with which a take-off has so far been made is approximately 56 tons and this weight was reached during the take off in Holy Rood for the trip to Horta. In spite of very squally weather it was possible slightly to throttle down the engines immediately after the take-off. Times for take-off at various all up weights are given in Fig. 18.

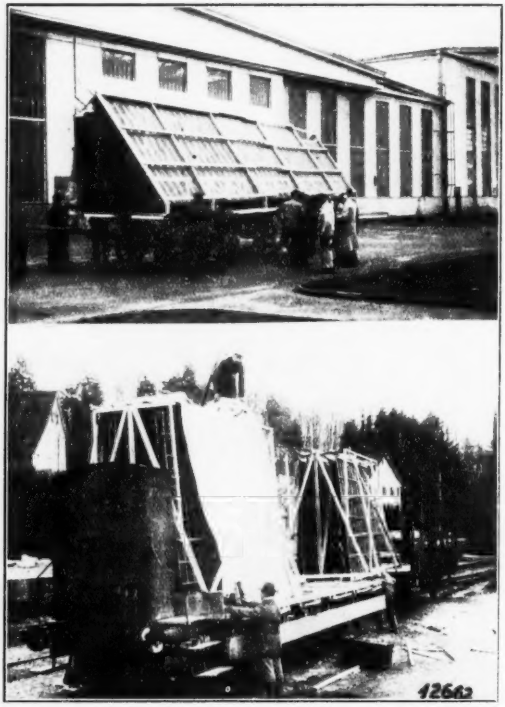


FIG. 16.

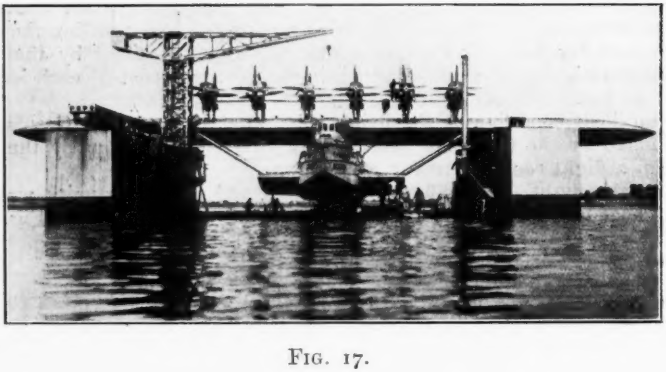


FIG. 17.

The diagram shows the take off curves for the Do.X 1a when she was first re-equipped with Curtiss Conqueror engines and also after the improvements to the engines, suggested by the Curtiss Wright Company, had been made.

This diagram includes a number of " take-offs " under unusual conditions. The influence of a tropical climate on the speed of take off was extraordinarily interesting. For instance, it takes the Do.X 1a 40 seconds to take off at a weight of 46 tons in European waters whereas 123 seconds were required in the tropical summer of Bolama. An average temperature of 80.6 degrees Fahrenheit was registered during the three weeks' period of take off tests at Bolama and the humidity of the air was nearly 100 per cent. The flying ship at a weight of 54 tons got on to the step reasonably quickly, but was unable to leave the water. A start at even 50 tons weight at Bolama proved absolutely impossible. From the diagram it will be observed that the rates of take off improved substantially after modification of the engines.

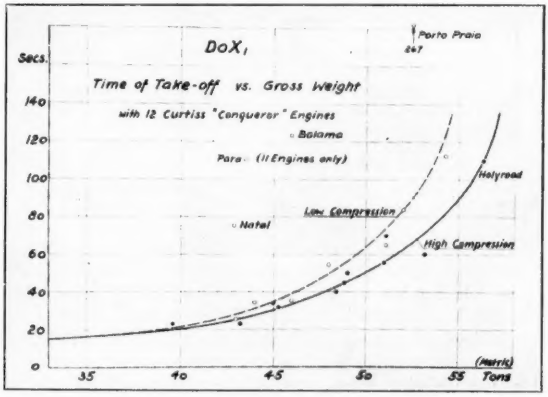


FIG. 18.

The average cruising speed of the Do.X 1a throughout the whole test period was 168 km. per hour and the average engine revolutions were 2,170 per minute. The all up weight of the aircraft fluctuated widely during the test. The average weight for the cruising speed I have just mentioned may be taken as about 47 tons.

Inaccurate statements regarding the boat's climb are I believe current. For instance, " Jane's All the World's Aircraft " for the year 1932 gives the service ceiling at 500 metres. As is well known the two boats ordered by Italy had, during delivery, to be flown over the Central Alps; moreover, Lake Constance is 400 metres above sea level. It is therefore perhaps not inopportune to make known the fact that the real ceiling is somewhat higher.

The average fuel consumption of the Do.X 1a, as calculated over the whole of the tests, can be taken as 7.45 kg. per kilometre. I am prepared to admit that we had reckoned on a considerably lower figure, and in the two Italian boats we were able to reduce the consumption to 6.95 kg. per kilometre. These fuel consumption figures apply when all engines are in use.

Useful Load Ratios

In Table II the weights empty of the three different types are given, and these were obtained by weighing.

TABLE II.

Group.	Do.X 1 with Siemens Jupiter.	Do.X 1 with Curtiss Conqueror.	Do.X 2 with Fiat A22 R.
Airframe weight comprising: Wings, struts, tail unit, controls, hull including "B" deck flooring, engine mountings, engine nacelles, exterior paintwork	19029	19094	19063
Engine installation according to Table 1	7007	8083	10103
Lubricating oil installation	340	485	474
Fuel installation	1200	1200	1200
Engine instruments comprising: Revolution Counters and petrol, lubricating oil and radiator gauges	229	254	264
Flying instruments comprising: Speed indicator, altimeter, inclinometer	36	36	36
Navigation instruments: Compass and navigation table ...	36	36	36
Lighting comprising: Source of electrical energy, lamps, wiring and generator	250	250	250
Miscellaneous equipment comprising: Accessories and instrument boards	90	90	90
Accessories equipment: Fire extinguishing installation, D.K.W. motor for W/T and lighting system, tool kits, special engine tool kits, covers for airscrews and engine nacelles	700	700	700
Communication equipment comprising: Soundproof W/T cabin, complete sending and receiving sets, emergency sending set, D/F set and signalling apparatus	370	370	370
Marine equipment comprising: Anchor and fittings, bilge fittings, cleats, towing fittings, safety appliances, water rudder	400	400	400
Furnishings comprising: Windows and flooring	200	200	200
Total weight	29887	31198	33185
Kgs. per cruising horse-power	8.03	6.26	5.32

Referring to the difference in the weight of these prototypes compared with the figures I gave in the course of my lecture in 1928, I would draw your attention to a comparison which I gave in this connection in my lecture to the German Scientific Aeronautical Association, the Wissenschaftliche Gesellschaft für Luftfahrt, in 1929 and which was published in the 1929 edition of the Association's Year Book.

With a structure weight of 31.2 tons for the Do.X 1a the greatest useful load is 24.8 tons. This corresponds to a useful load to total weight ratio of 44 per cent. The normal total weight for the Do.X 1a should be taken as 48.7 tons according to the experience we have so far gained.

The " take-off " at this weight then occurs in about 40 seconds under normal conditions and the proportion of useful load to total weight is 35.7 per cent.

I have endeavoured to establish the ratio of useful load to total weight in different types of modern multi-engined flying boats and landplanes. Unfortunately it is seldom possible to obtain the structure weight with any degree of certainty from technical publications—only in isolated cases—but I have frequently found this ratio in modern multi-engined aircraft to be between 26 and 38 per cent., so that the flying ship, with its 35.7 per cent., does not compare unfavourably.

The useful load per cruising horse-power works out at 3.38 kilogrammes for the Do.X. I have endeavoured to ascertain this ratio for other multi-engined aircraft and have arrived at a similar figure.

The petrol consumption of the Do.X 1a per ton kilometre of useful load is 0.431 kg., whereas that for certain other aircraft I know works out between 0.4 and 0.5 kg.

I would now like to summarise our experience with the flying ship up to the present:—

" Using the customary methods of calculation, and adhering strictly to the existing German regulations governing the factors of safety in the air and on the water, we have been able to build a flying boat with an all-up weight of 56

tons. The flying characteristics of this flying ship are absolutely normal; no unpleasant characteristics of any kind such as are occasionally found in smaller aircraft were observed during the flight—on the contrary, flying ships behave much better in bad weather than do some of the smaller boats that we know. The boat can be flown by one pilot for hours on end without undue fatigue; taking off and landing is quite normal and can be carried out by any pilot of average ability. The take-off and landing runs are remarkably short, and manœuvrability, as well as the behaviour at a buoy and while in tow, are all excellent. The highest useful load is 24.8 tons. The normal useful load is 35.7 per cent., and the maximum 44 per cent. of the total weight—a ratio which is well within the performance figures for smaller modern multi-engined aircraft.

"The fuel consumption under ordinary conditions of continual service is 7.45 kg. per km.

"The cruising speed is 168 km. per hour.

"The maximum distance that can be flown without paying load is 3,200 km."

The cruising speed, the fuel consumption, and the range have not proved to be substantially less than our anticipations, as is shown by the comparison given in Table III.

TABLE III.

COMPARISON OF CALCULATED PERFORMANCE GIVEN IN 1928 WITH PERFORMANCE OBTAINED IN PRACTICE.

	Lecture to R.Ae.S. 1928.	Flight Tests 1930-32.	Difference.
1. Maximum horse-power	6000 h.p.	7400 h.p.	+1400 h.p.
2. Maximum all up weight	54000 kgs.	56000 kgs.	+2000 kgs.
3. Maximum useful load	25800 kgs.	24800 kgs.	−1000 kgs.
4. Fuel consumption	6.10 kg./km.	7.45 kg./km.	+1.35 kg./km.
5. Cruising speed	185 km./h.	168 km./h.	+17 km./h.
6. Maximum range	4042 km.	3200 km.	−842 km.

Column 1 gives the figures which I quoted in my lecture to the Royal Aeronautical Society in the spring of 1928, the second column gives the figures obtained as the result of the test cruise with Do.X 1a.

The size of the ship made it impossible to introduce improvements during construction or test, which would have presented no difficulty in a smaller aircraft.

With a smaller single engined boat, for instance, it would have been quite a simple thing to try out two or three different airscrews. With the Do.X this would have meant the production of 24-36 airscrews. This applied eqally to every other detail of the engine installations and their accessories, for example the water and oil radiators.

The effect of making alterations to any part of a ship of that size may be gauged by the fact that approximately 300,000 working hours were required for the engineering work alone.

In comparing the performance of the flying ship Do.X with that of modern aircraft, it must be remembered that the ship, with all its construction details, was laid down as long as five years ago and that it was not possible to make any extensive alterations. In the meantime science has not stood still and it is obvious that the designs on which we are now working will include quite a number of improved features which it is anticipated will result in better performance and reliability. Considered from the present-day standpoint, the comparatively primitive aerodynamical design of flying ships built at that time render them particularly susceptible to those improvements in performance which have been applied in the meantime to a greater or lesser degree to most modern aircraft.

The size of our flying ship gives the crew and passengers a sense of security which is absolutely unknown in smaller aircraft during flights over

wide stretches of open sea. This feeling of security is an absolutely essential feature for any future regular traffic over long sea routes.

The need for air transport on long sea routes certainly exists and the establishment of air lines to span the ocean is certainly one of the most fascinating and satisfying problems with which air transport is faced.

For this problem, however, only the large seaplane, the flying ship, can be considered a satisfactory solution.

It is in this undeniable fact that I find sufficient satisfaction for the time and money that we have devoted to the development of the first flying ship.

Discussion

The President: He thanked Herr Schuettel and, through him, Dr. Dornier, very sincerely for the preparation and reading of his most interesting lecture. He felt sure that they had all been very impressed with the frankness with which he described and illustrated their failures and difficulties, and the modesty with which he claimed his triumphs. He thought that that would inspire the greatest confidence in the future work of Dr. Dornier and his staff.

He did not want to take any part in the debate himself, and he hoped that some of those members who had taken part in the last debate would be more careful. He had noticed that Dr. Dornier had a good memory, and that some of the things that had been said five years ago had sunk in, and none of them had been forgotten. He only mentioned that as a word of warning to those taking part in the debate; because he felt sure that he was expressing the wishes of all when he said that, although that was the second occasion, it was not the last occasion on which they hoped to welcome Dr. Dornier or one of his able representatives to lecture before the Royal Aeronautical Society.

Mr. Gouge (Chief Designer, Messrs. Short Bros.): He thought the Royal Aeronautical Society were to be congratulated upon the lecture which they had just heard. He himself had not taken part in the discussion five years ago, so he thought himself safe at the moment.

Though the German design differed greatly from the British design, there were one or two points in Dr. Dornier's lecture to which he would like to draw attention, and perhaps get some figures from Dr. Dornier. First, with regard to the damage to the stub wing, he (the speaker) had had experience of damage in England to wing floats, but never in his experience had the force been fore and aft; it had been either directly upwards or sideways. He did not know exactly why Dr. Dornier thought it was twist and perhaps the lecturer would explain that more clearly. He definitely thought that the experience of those in this country led to the conclusion that the force was upwards and sideways.

He was afraid that he had not had time to digest the advance copy sufficiently to make any really critical remarks; but with regard to what the lecturer (Dr. Dornier) had said, referring to the useful load it would appear that Dr. Dornier had obtained a useful load of something in the neighbourhood of 36 per cent. That, of course, was very good and was an indication of what one might expect from large boats; and although the boat with which he (the speaker) had the pleasure of dealing was not nearly so large as the "Do.X," it did weigh something like 70,000lbs., and on that boat they had got a useful load of approximately the same figure as Dr. Dornier had obtained.

There was another point that interested him, and that was the number of hours it took to design the "Do.X." 300,000 hours was a good long time, but in the case of the boat that he had had dealings with, although it was a smaller boat, it had taken something over 100,000 hours. That only went to prove that "red tape" was, if possible, a little worse in Germany than in England.

Air Commodore Cave-Browne-Cave (Director of Technical Development Air Ministry): He congratulated Dr. Dornier on his most remarkable achievement.

He (the speaker) also had not taken part in the discussion five years ago, and so he also felt safe. He knew that the great body of opinion had been that the " Do.X " would not be anything like as successful as it had been.

He would like to ask the lecturer about the carrying of fuel in the hull. Herr Schuettel had said that the fuel had been carried there to keep it away from the engines and also from the electrical equipment. He (the speaker) imagined that there must be a great deal of electrical and wireless equipment in the hull. One of the advantages of the policy adopted in this country of keeping petrol in the wings, was that it left the hull free from petrol fumes for such matters as cooking and smoking. He did not know how it was arranged in the German boat—whether they took any special precautions about cooking.

He had been very much impressed with the ingenious way in which the lateral stability of the " Do.X " was assisted by the cylinders suspended in the water. That seemed to him a very good idea.

He did not know whether Dr. Dornier could give any information about the anchor gear which had been carried in the boat; it seemed to him with a boat of that size the development of a satisfactory anchor and winch must be a very great problem. Did the boat ride at anchor, or did it use moorings? Certainly, from the length of time it was afloat and the route which it flew, it had created a remarkably fine performance on the water.

Major MAYO (Technical Adviser to Messrs. Imperial Airways): He could not help admiring the thoroughness of the review which the lecturer had been good enough to place before them.

He would have liked to hear a little more about the actual taking-off conditions experienced during the tour. For instance, it would be interesting to know a little more about the actual sea and weather conditions prevailing at Las Palmas when the damage was sustained. It seemed to him that in the case of this flying ship, with its very high taking-off speed, the question of its ability to take off in rough conditions was the question which would determine whether the ship was a practical proposition or not. The tour which had been carried out with very great success had been spread over a long time, and he would like to know how far, if at all, the delays were due to inability to tackle rough sea conditions. Unless a large flying ship such as this could maintain a high standard of regularity under the conditions likely to be experienced in practice, he did not think its high initial cost would be commercially justified.

One of the most interesting differences between Dr. Dornier's practice and British practice was in regard to the means provided for lateral stabilisation. He very much hoped that some other members taking part in the discussion would carry the comparison between the two methods a little further. In the case of Imperial Airways, they had always employed flying boats with wing floats, and had had practically no trouble with them. They had quite frequently had to deal with very rough conditions in the Mediterranean. There had been in the past one or two failures, but those had been due to quite definite causes which had since been eliminated. He thought he was right in saying that for the last few years they had had no trouble whatever. He ventured to suggest that the wing float method represented a considerable saving in structure weight, and would be interested to hear Dr. Dornier's views as to whether the sponson method could compare favourably with the wing float method on the basis of structure weight.

Major BUCHANAN (Deputy Director of Technical Development, Air Ministry): He confessed that he was one of the people who had taken part in the discussion in 1928, but he claimed that the remarks which he had made then were made with a proper sense of caution, and that they were not very much out of place. What he had said then was that he did not think Dr. Dornier expected to get all that he claimed in his paper, but that if he got anything near it he would be doing a great deal to advance the development of the flying boat—that he would

be doing a great deal more than any other man to develop the large flying boat if he could get approximately the figures which he had then given. They would see from the paper, from the comparison in Table III, that whilst Dr. Dornier had not actually achieved the figures that he gave in 1928, he had achieved a very close approximation thereto; and he (the speaker) thought he had done a great service to aviation and advanced the use of the flying boat as a vehicle for the transportation of people across the wide oceans.

He (the speaker) thought that the success that Dr. Dornier had achieved in keeping down the structure weight and carrying such a large proportion of useful load had exceeded the expectations of people in this country at the time when the paper was written. Some of that success, no doubt, was due to the very high landing speed of the " Do.X." He thought that the landing speed was of the order of 70 to 80 miles an hour, and that was more than they in England considered reasonable or practicable for flying boats. Nevertheless, there was no doubt that the seaworthiness of a flying boat did increase with size, and it might be that with large boats with many engines a higher landing speed was permissible than one would consider safe in the case of smaller boats.

He (the speaker), in addition to taking part in the discussion in 1928, had had the privilege of flying in the " Do.X," the first machine of the type, when it was fitted with " Jupiter " engines at Friedrichshafen some years ago. The experience had been a very interesting one. He had been very much impressed by the extraordinary feeling of security when flying over the sea in a large vehicle of that nature.

In conclusion, he thanked Dr. Dornier and also Herr Schuettel for coming and giving them the benefit of so much experience and adding so much to the knowledge of the flying boat problem.

Mr. C. G. Grey (Editor of " The Aeroplane ") : He would like to ask for information, and give an explanation, with regard to the climbing powers of the " Do.X," as Dr. Dornier had objected to the figure of 500 metres as the ceiling of the machine given in " All the World's Aircraft." He would like to know what the true figure was, and to explain that the figure in " All the World's Aircraft " had been passed by the Dornier Company. It had appeared in the 1931 edition and those pages had been sent for correction to the Dornier Company for the 1932 edition and had been returned with that figure unaltered.

Possibly the figure represented the ceiling of the " Do.X " in its original state with full load and the Continental radial engines. When the ships which were built for Italy flew over the Alps to Italy they had Italian engines, and he imagined that they did not carry full loads. Also everybody knew that a horse would go better towards its own stable, which might account for the Italian horse-power.

Dr. Lachmann (Messrs. Handley Page) : He had been very impressed with the way in which detailed figures of weight had been given. Such figures were usually carefully guarded by aircraft manufacturers and it was therefore often impossible to make instructive comparisons of really technical value between types of different construction and size.

The lecturer had mentioned that it had taken only four weeks to repair the large wing in the open. He (the speaker) thought that this was an amazingly short time, because they all knew that it sometimes took very much longer to repair a much smaller wing in well-equipped shops.

Mr. W. O. Manning (Fellow) : Could the lecturer define the worst sea that the boat could get off with a full load, so that they could get some idea of what he thought were the worst conditions which the boat could be expected to withstand without danger?

The lecturer had referred to the question of petrol in the hull. British flying boats in the past had carried petrol there, but the conclusion had been come to that it was definitely dangerous—he was referring to the " F " and " P " boats

and certain others. It was not always possible under ordinary conditions to find a leak as soon as it occurred, and it sometimes happened that there was a leak in, say, a petrol connection at the bottom of the tank, and when that happened one got a little petrol into the bilge, and when it got there there might be an explosive mixture. He thought that putting the tanks on the wings made things perfectly safe from that point of view.

With regard to the centre of gravity, it was perhaps one of the disadvantages of the Dornier type of boat that care had to be taken to keep the centre of gravity especially low; otherwise he supposed the short stub wings would have to be considerably larger than they were; but even then the centre of gravity must be in a very different place when the tanks were empty from what it was when the tanks were full. He took it that when the tank was empty the boat would be perfectly safe from the point of view of stability.

The speaker referred to the fact of it being impossible to avoid an occasional starting of a rivet, and it would seem rather dangerous to put petrol in the double bottom, because when the boat was on the water, water might get into the petrol tank, and when the boat left the water there would be petrol running out.

He had been one of those who had spoken on the previous occasion, but, so far as he remembered, he had said nothing for which he thought he ought to apologise at the moment. He would like to repeat one question which he asked on that occasion. He had then drawn attention to the fact that the wings of the machine were rectangular in plane, and as to whether considerably lighter wings could not be used. If the plan form of the wings were tapered Dr. Dornier had answered that question by saying that it was a question of economy in manufacture.

He would like to know if there was any special reason for the stub wings being blanketed off square.

In conclusion, he thought it had been a remarkable feat to design the boat in the way Dr. Dornier had done, and to make such a success of it the first time. It appeared as a rough calculation, that in full flight the boat would lose weight at the rate of 30lbs. a minute in petrol, and that an additional passenger would only reduce the duration of flight by about six minutes.

Mr. Gordon England (Member of Council): As a passenger he had had an opportunity of flying 1,250 miles non-stop in the "Do.X," and as a result of this experience one of the most important things, to his mind, was the question of noise. He asked Herr Scheuttel whether in later types they had made any real attempt to tackle the noise question. He confirmed everything that had been said about the extraordinary feeling of safety one experienced while flying in the "Do.X." During the flight Dr. Dornier and Capt. Christiansen had very kindly given him the complete run of the ship, and had even allowed him to take control. The condition of the ship, its ease of control, its extraordinary steadiness in the air, the spaciousness, and appointments were splendid, but the outstanding thing left on his mind, looking at it from the point of view of commercial transport, was the intolerable noise in any part of the ship; there was no part where one could say there was any comfort from that point of view. In every other respect it certainly was a most amazing ship.

He had been particularly interested in the slide giving the "curve of taking off;" because when the "Do.X" left Calshot for Berlin she took exactly 58 seconds in quite poor conditions to take off, and she had then a load of 48 tons; this corresponded exactly to the calculated performance curve. He had made several flights in the ship, and one thing which had very much impressed him was the ease with which she took off; but he thought that a far more extraordinary thing was the ease with which she could be landed. On one particular flight, although she landed at 82 miles an hour, or something approaching that figure, out of a lot of empty wine glasses on several of the tables in the cabins—light sherry glasses—not a single one had been displaced. That was during a landing on the Solent, and he thought it was a remarkable tribute to the steadiness of

the ship. When she landed in Berlin at the end of her world flight, it had been literally impossible, although he watched very closely, to detect the actual moment of contact with the water.

Frankly, he thought that if the question of noise could be tackled and settled satisfactorily, there would be a very useful life commercially for the " Do.X," but until that matter had been dealt with it was a very questionable problem as a commercial vehicle.

Colonel FELL (Rolls-Royce Ltd.) : One thing which concerned engine builders rather seriously was the question of shaft drives. Dr. Dornier had briefly touched on that point and had stated that very great advantages would be obtained if he could place the engines inside the wing. He (the speaker) took it that that would involve some form of shaft drive. There were, of course, two main types of shaft drive—namely, the straight drive off the engine, and the bevel drive. It would be very valuable to engine builders to know which, if either, of those types of shaft drive would be worthy of development. A good deal of work had been done from time to time, both in design and actually in manufacture, with regard to testing the shaft drive, and it seemed to him that there was no real fundamental difficulty about producing such a drive if there was a certainty that such a thing would be valuable to the aircraft constructor. He thought that if Herr Schuettel could say something about that in his reply, it would be of great interest to engine builders.

Sir A. VERDON-ROE (*communicated*): The " Do.X " rudder, elevators and ailerons are all balanced with a modified form of balancing device that was known about 1915 as the " Avro Balancer " which is an improvement on the Avro device when used for ailerons and rudders; but he thought Dr. Dornier would find quite as good, if not better results would be obtained, if he fitted the ailerons as the Avro people did.

The balance in this case was fixed direct to two streamline struts projecting from the aileron well forward so that when the aileron goes down the balanced portion rises, offering its under surface at a positive angle helping to balance the aileron, but when the aileron is raised, the balanced portion offers its upper surface at a negative angle, and when close to the surface causes extra drag owing to the angle relatively to the main plane's upper surface. This is not detrimental as it helps the turn as in the D.H. differential control.

In the Dornier method the balancing surface is linked up so as to be about horizontal with the wing surface when the aileron is raised, and is then neutral, the balancing effect having to be obtained entirely from the balancer on the aileron that is depressed on the other side.

He suggested Dr. Dornier may care to give the simplified form of balance, that has been used by the Avro firm from time to time, a trial.

The detachable sections of wing covering employed by Dr. Dornier seems an excellent idea, and it would be interesting to know whether he finds this method more economical as regards weight. It certainly appears to be, as so much neutral axis is removed and the struts are of short length from their connecting points.

He would like to ask Dr. Dornier if he was building another machine of the same tonnage if he would increase the aspect ratio of 5.45 and employ a tapered wing.

REPLY TO DISCUSSION

Herr SCHUETTEL, in replying to the discussion, said he hoped the audience would understand that the right to answer questions should be reserved to Dr. Dornier himself; but, nevertheless, he would try to answer the questions as far as he could.

Replying to Mr Gouge: it had actually been a twist that happened to the boat during the take-off at Las Palmas.

With regard to the question of storage of fuel in the hull: Dr Dornier did not feel very badly about it, because he had a deck in between and the fuel was stored on the bottom below the last deck, and everything else was fully isolated from the fuel. Electrical cooking stoves were carried in the rear part of the boat.

One of the speakers had observed that the sea conditions or the take-off speed might be a limiting factor for seaplanes. As things were, nature was imposing a limit when there were big steamers coming into port with broken windows and broken davits, and so on, so that it was no wonder that natural conditions were a limiting factor for a much smaller thing like a flying boat. The actual cruise of the " Do.X " had not been so much affected by difficulties in taking off, except in regard to the difficulty of taking off owing to the temperature and humidity in tropical Africa. Due to commercial considerations, in most harbours in Europe the boat had been thrown open and visitors had been allowed to come aboard, and sometimes 3,000 or 4,000 visitors a day had visited the boat. That had taken up some time and was a most annoying factor from the purely technical standpoint.

With regard to what Mr. Grey had said, he thought there was some mistake. A ceiling of 500 metres certainly had never been given out by the Dornier Company. It was quite natural that a ceiling of some 10,000 feet corresponded to a half-loaded ship, but the same ship could obviously not have a ceiling of only 100 metres above the level of Lake Constance, fully loaded.

He was sorry that he could not tell the audience the exact height of the seas in which the " Do.X " had taken off; because he had not been present on that flight and was away from the Dornier Company at the time; but he supposed that Dr. Dornier himself would tell Mr. Manning all about it in his answer.

With regard to the form of the wing, the present form had been decided upon on weight considerations. The cut-off on the stub wings had been partly due to strength considerations, and partly because one tried to make the stub wing act as a kind of step when taking off. Besides, when the boat was taking off lightly loaded, the condition of the stub wing should be approximately the same as it was when it was fully loaded.

Dr. Dornier himself had remarked about the noise question, but, so far as he (the speaker) knew, nothing had been done about that question so far as the Italian ships were concerned, because they were not used for commercial purposes; he understood they were part of the Italian Navy.

Until the present time they had not developed the shaft drive. The figures which had been given of the increase in speed had only been calculated in order to show what could be done if the engines were to be put in the wing, and he thought that kind of drive was certainly worthy of development.

Dr. Dornier's Reply to Discussion

Dr. Dornier expresses his deep regret that he was unable to attend the lecture personally and to enjoy British hospitality. He appreciated very much the reception given to his representative.

The two figures for the engineering hours of the " Do.X " and the R6/28, as given by Mr. Gouge, should not be directly compared. The figure for the " Do.X " includes all the preliminary project work and the extensive research as well as the redesign of the power plant, including nacelles and airscrews. The comparable figure would thus be somewhat lower than 300,000 hours.

The anchor weighed 220lbs.; it was assisted in bad weather by a ship's anchor borrowed from port authorities when a buoy was not available. It is rather difficult to generalise about seaway, as conditions are apt to differ radically as far as magnitude and direction of wind, of seaway as such and of swell are concerned. At Las Palmas the direction of take-off had been given by geographical conditions, and wind as well as a semilateral swell came in from different directions.

Otherwise a swell of 7 to 10 feet did not prevent a take-off with fully loaded ship.

Sponsons require some additional weight when compared to small wing tip floats, but Dr. Dornier feels that it is fully justified by the increased safety while taxying or in case of an emergency landing on high seas. The initial water stability of the ship empty is only little less than for the ship loaded as the decrease in displacement counteracts a decrease of the metacentric height.

The wings might have become lighter with two spars instead of three, which had been chosen for additional safety. A tapered plan form was not considered advisable for the semi-cantilever wing, where the presence of struts has already the effect of a reduction of the maximum bending moment. Besides, the advantage of exchangeable wing panels would have been lost.

The Dornier works started out from an aileron balance of the type suggested by Sir A. Verdon-Roe. Their present balance is parallel to the wing for zero position of the aileron. Besides the effect described by Sir A. Verdon-Roe, it is easily adjusted and different ratios of angular movement are obtained according to the choice of the lever arms. The present aspect ratio of the wing has been found satisfactory; the tapered plan form would be used in the case of a cantilever wing.

A SIMPLE APPROACH TO THE WING FLUTTER PROBLEM

BY

B. LOCKSPEISER, M.A.

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PART I.

FLUTTER OF A WING WITH LOCKED AILERON

1. *Oscillations in Still Air*

Let us first consider the oscillations, in still air, of a monoplane wing whose aileron is supposed locked to the wing in such a way that it behaves as though it were an integral part of the wing structure. When the wing is displaced from its position of equilibrium and released it will, in general, vibrate both in flexure and torsion. The initial displacement may be purely flexural, but if the inertial forces called into play, over any wing section, produce a twisting moment about the centre of twist (*i.e.*, the centre about which the wing section twists on the application of a pure torque at that section)[1] torsional as well as flexural oscillations will be set up. Inertia, in general, robs the two kinds of oscillation of their independence, and, when they are interdependent, we may conveniently speak of " inertial couplings " between the two motions. In still air these vibrations must, of necessity, die down. One part of the wing may gain energy at the expense of another, but the store of elastic energy given to the wing by the initial displacement must grow progressively less as the wing does work against the viscous air damping and structural hysteresis forces.

The following diagram is intended to provide a convenient representation of the behaviour of a wing under the conditions just described.

2. *Oscillations in a Wind*

If the wing is set in oscillation in a wind the forces against which the wing does work are still operative. Since the oscillation of a wing structure in still or moving air involves a dissipation of energy we may infer that if a wing continues to oscillate with either a constant or increasing amplitude a *flow* of energy is available to it from outside. We know, from observation, that if a wing be placed in a stream of moving air (in a wind tunnel, for example) conditions may arise whereby the wing displaced from equilibrium will oscillate with increasing amplitude limited only by the fracture of the structure. This phenomenon is known as wing flutter. We may conclude then, that when flutter occurs the wing has access to an external source of energy from which energy flows into the wing at an increasing rate. The only possible source of this energy is the wind.

The occurrence of wing flutter therefore indicates, in the first place, some self-acting process whereby the transfer of energy from the wind to the wing necessarily produces circumstances favourable to the transfer to further energy. Normally these circumstances are absent. A wing in steady flight, for example, is elastically deformed and during deformation takes a certain amount of energy from the wind, but in the circumstances thus created there is nothing which

[1] For some cross-sections the centre of twist coincides with the flexural centre, *i.e.*, the point at which the application of a force displaces the section flexurally without twist, and the single term " flexural centre " is often used in reference to either centre. There is no justification for a general assumption of the coincidence of the centres in the case of wing sections, and, in this paper, the nomenclature appropriate to each centre will be used.

makes possible or inevitable a further transfer of energy. How does this self-acting process arise?

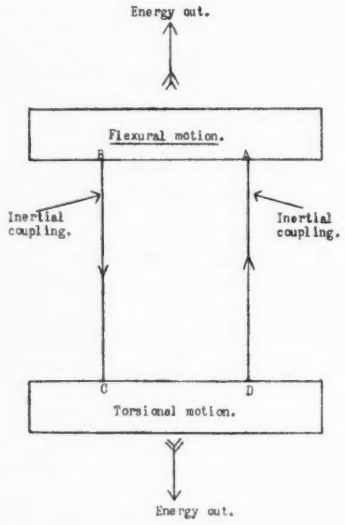

FIG. 1.

(The arrow attached to a coupling indicates the direction in which the coupling is effective.)

3. *Oscillations in a Wind of a Wing Initially Disturbed in Flexure*

Consider a wing in a stream of moving air of velocity V and suppose that, owing to some accidental disturbance, the wing begins to oscillate, say, in flexure. A change in the incidence of the relative wind occurs on account of (*a*) flexural displacement and (*b*) flexural velocity. That due to (*a*) is negligible for small displacements, but the change due to flexural velocity must be taken into account.

If z is the displacement in flexure, at any instant, of any section, $\dot{z}/V$ represents the change in the angle of incidence of the relative wind, and the additional force which comes into play on the section in unstalled flight owing to flexural velocity is therefore approximately proportional to $(\dot{z}/V)\,V^2$ or $\dot{z}V$. This force will, in general, exert a twisting moment about the centre of twist and as it changes sign with the sign of $\dot{z}$ the effect will be to set up a forced torsional oscillation of the wing.

Here, then, is a process whereby energy may be transferred from the wind; and we note also, the existence under these conditions of a new kind of coupling —an aerodynamic coupling—between flexural and torsional oscillations. The energy, however, is not necessarily conserved by the wing as torsional energy. It may, in part, be used to oscillate the wing in flexure. For consider the inertial forces on a section whose angular displacement in torsion about the centre of twist at any instant is θ. The sum of the inertial forces is $\Sigma m\dot{x}\dot{\theta}$ giving rise to a flexural moment about the wing root of $y\Sigma m\dot{x}\dot{\theta}$ whose sign changes with that of $\dot{\theta}$. Inertia may therefore effect a transformation of energy within the wing whereby part of the torsional energy may appear as flexural energy, thus renewing the initial conditions under which a transfer of energy

of wind to the wing can be effected. In this way a cycle of events may be set up involving a continuous flow of energy to the wing. In general we shall not expect the mean value of this energy flow to be constant. A constant flow may be possible under a particular set of physical conditions, in which case the wing will oscillate in flexure and torsion with constant amplitudes (provided the stresses involved are below the breaking stresses of the structure) dissipating energy at a rate exactly equal to that at which it receives energy from the wind. Such a state can be reproduced in a wind tunnel by a careful adjustment of wind speed. This speed is critical for the wing and is the critical flutter speed. Any small departure from it one way or the other upsets the conditions of constancy of energy flow and leads either to progressively diminishing or increasing amplitudes of oscillation.

4. *Oscillations in the Wind of a Wing Initially Disturbed in Torsion*

An initial torsional disturbance of the wing may give rise to a similar energy cycle. In this case there is a change in the direction of the relative wind due to the angular displacement and the angular velocity of the wing section arising out of its torsional motion. This results in a change of lift and an additional force from the wind therefore tends to displace the section in flexure. This implies the existence of a second aerodynamic coupling. Inertia may, in a manner similar to that previously described, compel the movement of the section in torsion, thus completing the cycle and renewing the conditions favourable for a further input of energy.

5. *Graphical Representation of the Cycles*

We are now in a position to amplify Fig. 1 to include the aerodynamic couplings, thereby providing a convenient graphical representation of the two cycles just described. The former of the cycles, initiated by a flexural displacement from equilibrium, can be represented by *AEFDA* and the latter, in which the displacement is initially in torsion, by *CHGBC*.

The two cycles, *AEFDA* and *CHGBC*, do not exhaust the possibilities; one other, *GEFHG*, may also operate to cause flutter, for clearly, in this case also, the conditions whereby energy is drawn into the cycle may be continuously renewed. These are the three possible self-acting cycles in contact with a source of energy.

Whether or no the cyclical renewal of initial conditions reinforce the effects which arise out of these conditions depends on the shape, stiffness and mass distribution of the wing. We might endeavour to prevent flutter, which occurs when the phase relationships of the events of the cycle are favourable, by so designing the wing that they are invariably unfavourable; on the other hand, an obvious (and probably easier) course suggests itself in interrupting the chain of cyclical events. If the cycles are not physically possible there can be no flutter.

6. *Elimination of the Cycles*

Our purpose then is to destroy the three possible cycles. We notice that flexural and torsional motions are common to all three cycles and if we could suppress either of these motions no cycles would be possible. This solution is obviously denied to us for we cannot make a rigid wing. We turn, therefore, to consider the possibility of suppressing the couplings.

Since the suppression of one coupling is sufficient to destroy a cycle not all the couplings need be eliminated in order to achieve our purpose. It is necessary and sufficient to suppress either

(*a*) both aerodynamic couplings *EF* and *GH* simultaneously, or

(*b*) one aerodynamic coupling and one inertial coupling in pairs *EF* and *BC*, or *GH* and *AD*.

It is of interest to note that the elimination of both inertial couplings only, leaves a possible cycle *GEFHG*. Flutter can occur in the absence of inertia.

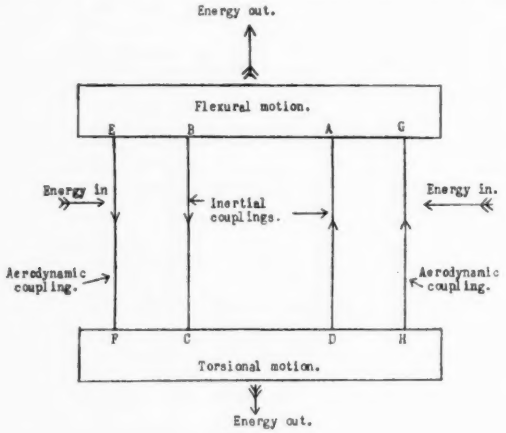

FIG. 2.
(The arrow attached to a coupling indicates the direction in which the coupling is effective.)

7. *The Aerodynamic Couplings*

We will examine the possibility of suppressing the aerodynamic couplings. Let us first turn our attention to that represented in the diagram by *EF*. We have seen how, owing to a change in the direction of the relative wind arising from flexural oscillation, forced torsional oscillations will, in general, be set up. In a particular case, however, the moment about the centre of twist, for each section, of the additional aerodynamic forces due to the flexural velocity, giving rise to these torsional oscillations can be reduced to zero. The aerodynamic forces we are considering are not those proportional to V^2, which operate steadily on the wing on account of its forward velocity, but those additional forces proportional to $\dot{z}V$ for any section. For these latter forces there is below the stall, a centre for every section, called the centre of independence, about which the effective moment is zero. If, therefore, the wing can be built in such a way that the centre of independence coincides section by section with the centre of twist, torsional energy will not be available to the wing on account of its flexural velocity. This procedure therefore checks one of the two sources of energy supply and breaks the aerodynamic coupling *EF*.

An examination of the nature of the second aerodynamic coupling *HG*, on the other hand, shows that it cannot be disposed of in the same way. For the angular velocity and displacement of a section must produce a change of lift, and therefore inevitably a change of flexural moment on the section about the wing root. The coupling *HG* must, therefore, always be operative. We cannot suppress both aerodynamic couplings simultaneously. Course (*a*) therefore is not possible and only course (*b*), the suppression of one aerodynamic coupling and the appropriate inertial coupling is open to us for the prevention of flutter. We have already eliminated the aerodynamic coupling *EF* and the inertial coupling which must be eliminated simultaneously is *BC*. This we are at liberty to do.

8. *The Inertial Couplings*

If the displacement in flexure of any section at any instant is z, and x, y are

the co-ordinates of a small wing mass m in the section, with reference to two orthogonal axes, one passing through the centre of twist and the other the wing root chord respectively, the equation

$$\sum_s m\ddot{z}x = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $\sum_s$ denotes summation over the section, expresses the condition that the twisting moment about the centre of twist due to the inertial forces of the section in flexural movement, vanishes.

Equation (1) reduces to

$$\ddot{Z}\sum_s mx = 0, \ i.e., \ \sum_s mx = 0.$$

If, therefore, the condition $\sum_s mx = 0$ is satisfied for every section of the wing the inertial coupling BC is eliminated; this condition is satisfied when the section is mass balanced about its centre of twist.

We thus reach the conclusion that flutter of a wing structure carrying a locked aileron cannot occur in unstalled flight if every wing section is so constructed that the centre of independence coincides with the centre of twist and if, further, every section is mass balanced about this centre.

It is of interest to note that the satisfaction of the condition $\sum_s mx = 0$ also breaks the inertial coupling DA, *i.e.*, the inertia of torsional movement cannot give rise to flexural motion. For if θ be the angular displacement in torsion of any section at any instant, the equation

$$\sum_s mx\ddot{\theta} \, . \, y = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$\text{or } y\ddot{\theta}\sum_s mx = 0, \ i.e., \ \sum_s mx = 0,$$

expresses the condition that the inertial forces on the section in torsion exert no flexural moment about the wing root.

If, therefore, $\sum_s mx = 0$ holds for every section of the wing, flexural and torsional oscillations of the wing in vacuo[2] are independent. The one can never give rise to the other.

9. *Inertial Conditions for "Semi-Rigid" Wing*

It may not be always necessary to treat the wing section by section for, if the laws of flexure and torsion are known, conditions satisfying the requirements may be obtained relating to the wing as a whole. Thus, if the wing be of the "linear semi-rigid"[3] type the displacements in flexure and torsion of every section can be defined in terms of those of the wing tip section. The angular flexural displacement (ϕ) is uniform over the semi-span (s) whilst the angular torsional displacement of any section distance y from the wing root is $y\theta/s$, θ being the displacement in torsion of the wing-tip section. The inertial conditions corresponding to those obtained above are now

$$\phi\sum_w mxy = 0,$$

$$i.e., \ \sum_w mxy = 0 \quad . \quad . \quad . \quad . \quad . \quad (3)$$

to eliminate the inertial coupling BC and

$$(\theta/s)\sum_w mxy^2 = 0$$

$$i.e., \ \sum_w mxy^2 = 0 \quad . \quad . \quad . \quad . \quad . \quad (4)$$

---

[2] In still air m must be corrected for virtual mass.

[3] *i.e.*, distorts so that straight lines in the direction of the span remain straight, flexure occurring only at the root. See "The Flutter of Aeroplane Wings," Frazer and Duncan R. & M. 1155, p. 19.

to eliminate the inertial coupling DA, where $\sum_{w}$ denotes summation over the wing, and the reference axes are the axis of twist and the wing root chord.

The conditions for eliminating both inertial couplings are no longer identical. However, we are obliged to eliminate only one inertial coupling, namely, BC, and the required condition, therefore, is that the product of inertia of the wing about the wing root chord and axis of twist should vanish. If $\sum_{w} mxy$ is not zero a mass M can be placed in a position whose co-ordinates are X, Y, so that

$$MXY + \sum_{w} mxy = 0$$

There is no theoretical restriction on M, X and Y, other than on their product, and it is to be noted that the procedure of reducing the product of inertia to zero by the use of a balancing mass does not necessarily result in locating the C.G. of the wing on the axis of twist. The conditions, in this case, which allow freedom in the location of the balancing mass relate to a wing whose laws of flexure and torsion are simply linear, whereas those previously found (which really amount to each section being provided with its own balancing mass) relate to an elastic wing whose laws are either unknown or too complicated to deal with theoretically. We may expect cases in between where the satisfaction of the conditions require a mass to be placed at some particular point in the wing.

10. *Conclusions*

The aerodynamic and inertial conditions at which we have arrived for the absolute prevention of wing flutter may be difficult to fulfil in practice. This is especially true of the aerodynamic condition. It therefore becomes advisable to do whatever is possible to raise the speed at which flutter will occur. Dimensional theory shows that the flutter speed varies with the square root of the structural stiffness and consequently there is an advantage to be gained by increasing all the stiffnesses as much as possible.

We may, therefore, summarise the conclusions regarding wing design as follows:—

(1) Every wing section should be mass balanced about its centre of twist. For the semi-rigid wing the mass distribution of the wing should be such that the wing product of inertia referred to the axis of twist and the wing root chord[4] vanishes. In all cases the ailerons should be regarded as an integral part of the wing.

(2) Coincidence, for every section, of the centre of independence and the centre of twist.

For a wing carrying an aileron which can be locked to the wing these two conditions are necessary for the absolute prevention of flutter in flight below the stall. If they cannot be satisfied simultaneously we can raise the speed at which flutter will occur by increasing the structural stiffnesses.

The argument does not hold for conditions above the stall. Assuming the necessary aerodynamic adjustments to the wing can be made for conditions below the stall, flutter might still be possible above the stall. For the positive damping associated with torsional oscillations below the stall may change sign beyond the stalling angle. The " singing " of a rafwire when yawed in the wind at an angle greater than the stalling angle is an example of this type of oscillation, in one degree of freedom—in torsion.

The oscillations which may arise from resonance have not been taken into account in the foregoing treatment. A resonator itself is a source of energy supply and under appropriate conditions could cause wing oscillations of increasing amplitude. But if such sources of periodic energy supply as exist do

[4] In the case of a biplane the approximate nodal chord replaces the wing root chord as an axis of reference.

not cause wing instability of this sort in still air they will not lead to instability in flight below the stall, provided the wing is adjusted according to the conditions already established. Above the stall where flutter, as we have seen, cannot be ruled out, the effect of resonance is to advance its onset. Flutter will occur at a lower speed and one which may be low enough to be realised in stalled flight. Information on the resonating frequencies of wings is rather scanty, but, such as it is, leads to the conclusion that the possibility of resonance cannot be ignored. Increasing the wing stiffnesses, thereby obtaining, at the same time, the advantage of a higher flutter speed, appears to be the most suitable way of avoiding a resonating frequency, should it occur.

So far no reservation has been made in the foregoing treatment regarding the elastic properties of the wing structure. But some limitation is, nevertheless, implied in the argument. For the method of adjusting the wing section by section, in the manner described, is available only when pure flexural and torsional motions are possible for all sections simultaneously. That is to say, when the loci of the centres of twist and flexural centres,[5] respectively, of the sections are straight lines at right angles to the root chord. This brings into existence two wing axes, the former of which is not displaced in flexure by the application of a pure torque to the wing, and the latter being that along which a normally applied load produces no torsional displacement of the wing. In the absence of such axes the terms " torsional displacement " and " flexural displacement " have no real meaning when applied to the wing as a whole and the validity of the argument is therefore subject to the limitations imposed by these considerations.

Part II.

Flutter of a Wing with Unlocked Aileron

1. *Conditions for Effective Replacement of Mechanical Aileron Locking*

We have now to introduce the aileron into the problem, for the original supposition of an aileron mechanically locked to the wing is not realised in practice. Existing mechanisms of aileron control do not provide the necessary irreversible characteristic. The control cables are elastic and a certain amount of backlash is generally present. But if we imagine the irreversible mechanism in being and consider the aileron in a wind necessarily moving as part of the wing in flexural and torsional oscillations, we see that the irreversible nature of the mechanism becomes superfluous in one particular set of circumstances, namely, when the change of hinge moment of the aerodynamic and inertial forces on the aileron due to the oscillations is zero. Theoretically, then, if we can satisfy this condition we can effectively obtain an irreversible mechanism and the aileron will behave as though locked to the wing.

We might take advantage of the moment due to the air forces to partly counterbalance that due to the inertial forces, but this procedure carries with it the handicap of endeavouring to eliminate over a wide range the balance of two opposing variable moments. The separate elimination of the hinge moments, aerodynamic and inertial, appears the more promising line of attack.

2. *Elimination of the Aerodynamic Hinge Moment*

The aerodynamic forces on the aileron with which we are concerned are similar in character to those previously discussed in the case of the wing. The aerodynamic hinge moment brought into play, on account of flexural oscillations, arises from flexural velocity which alters the angle of incidence (α) of the relative wind by an amount, constant at any instant, over any particular section of the aileron and the corresponding section of the wing. Torsional oscillations produce

[5] See footnote 1.

an aerodynamic hinge moment due to both a change in the angle of incidence (α) and the angular velocity (q) of the aileron. The condition we desire, of zero change of aerodynamic hinge moment due to oscillations, will be satisfied when $\partial H/\partial \alpha = 0$, and $\partial H/\partial q = 0$, H being the aerodynamic hinge moment. It is doubtful whether for existing ailerons, a hinge position can be found to enable these conditions to be satisfied simultaneously and it will probably be necessary to choose some compromise position. Special experimental knowledge appears to be necessary for the determination of such a position and the problem may also call for new work on aileron design. The hinge position so determined would, however, probably conflict with general design requirements by producing an over-balanced control. But this difficulty could, theoretically, be overcome by spring control (without backlash) between the aileron and the wing by means of which $\partial H/\partial \xi$ (ξ being the aileron angle) could be brought to any value desirable on general grounds, without imposing restrictions on the choice of hinge position.[6] The satisfaction of the necessary conditions $\partial H/\partial \alpha = 0$ and $\partial H/\partial q = 0$ may be difficult to accomplish, but may not be inherently impossible. We will assume that the position of the hinge axis and the design of the aileron are favourable to the reduction of the aerodynamic moment to a small quantity and that the stiffness of the mechanical control is sufficiently high, and backlash small enough to render negligible the movement due to the residual moment.

3. *Elimination of the Inertial Hinge Moment*

We now proceed to adjust the inertial forces. The wing having already been made independent of the wind we can make these adjustments in still air. Further, the wing having been constructed on the lines previously discussed, flexural and torsional oscillations are independent modes of vibration in still air, and we are therefore justified in making the aileron inertial adjustments in flexure and torsion separately. If we attempted to effect this experimentally, we should endeavour to adjust the mass of the aileron and its distribution in such a way that, when the wing was forced into flexural and torsional oscillations in turn, the aileron behaved as though locked to the wing. As in the case of the wing, however, we can determine the theoretical conditions which must be satisfied.

Let $x_a y$ be the co-ordinates of a small aileron mass m referred to the hinge axis and wing root chord as axes,
z the flexural displacement of any section of the aileron,
θ the corresponding angular displacement in torsion, and
a the distance between the hinge axis and the centre of twist of the section (positive when measured forward from hinge axis).

For flexural oscillations the condition for zero hinge moment due to inertial forces on the section is expressed by

$$\sum_s m\ddot{z}x_a = 0$$

$$\text{or } \ddot{z}\sum_s mx_a = 0$$

$$i.e., \quad \sum_s mx_a = 0 \qquad . \quad . \quad . \quad . \quad . \quad (5)$$

where $\sum_s$ denotes summation over the section.

For torsional oscillations the corresponding condition is given by

$$\sum_s m\,(a + x_a)\,\ddot{\theta}x_a = 0$$

$$\text{or } \ddot{\theta}\sum_s mx_a\,(a + x_a) = 0$$

$$i.e., \quad \sum_s mx_a^2 + a\sum_s mx_a = 0 \qquad . \quad . \quad . \quad . \quad . \quad (6)$$

[6] For a discussion of the conditions under which aileron spring control may reduce flutter speed, see R. & M. 1155, p. 142.

Equations (5) and (6) must be satisfied simultaneously for every section—clearly an impossibility, for $\Sigma_s mx_a^2$ (the moment of inertia of the section about the hinge axis) cannot be zero, and a will always be positive in practice. The nature of this part of the aileron problem, therefore, also demands a compromise to effect an approximate solution. The expedient of attaching a small negative value to $\Sigma_s mx_a$ and reducing the moment of inertia to the lowest possible value appears to be a reasonable compromise.[7] $\Sigma_s mx_a$ is negative when the C.G. of the section is ahead of the hinge axis. Equations (5) and (6) are approximately satisfied, therefore, when the C.G. of every section of the aileron is just ahead of the hinge axis, whilst simultaneously the moment of inertia is reduced to the lowest possible value. Small chord ailerons are favourable to low moment of inertia and are to be preferred on this account (the increase in the value of "a" which may be involved is of no consequence as $\Sigma_s mx_a$ is adjustable).

4. *Inertial Conditions for Semi-Rigid Wing and Rigid Aileron*

As in the case of the wing inertial adjustments, a knowledge of the laws of flexure and torsion may enable the necessary conditions to be satisfied more simply. In the particular case of the "semi-rigid" wing type with linear laws of displacement and a rigid aileron pivoted at its ends, the conditions to be satisfied are given by

$$\ddot{\phi}\Sigma_a mx_a y = 0$$

$$\text{or } \Sigma_a mx_a y = 0 \quad . \quad . \quad . \quad . \quad . \quad (7)$$

where Σ_a denotes summation over the aileron, and

$$\ddot{\theta}\Sigma_a mx_a\,(x_a + ay/s) = 0$$

$$\text{or } \Sigma_a mx_a^2 + (a/s)\,\Sigma_a mx_a y = 0 \quad . \quad . \quad . \quad . \quad (8)$$

The simplified wing does not rid us of our dilemma for equations (7) and (8) cannot be satisfied simultaneously. Compromising in the same manner as previously, the conditions to be satisfied simultaneously are (*a*) $\Sigma_a mx_a y$ (aileron product of inertia about the hinge axis and wing root chord) slightly negative, and (*b*) $\Sigma_a mx_a^2$ (aileron moment of inertia about the hinge axis) to be as small as possible. The ailerons can be treated as a whole instead of section by section. The product of inertia of the aileron can be adjusted to the required value by a bob weight attached in an appropriate position, the considerations governing the position of the weight being exactly similar to those previously found for the similar wing problem. Simultaneously the moment of inertia of the aileron about the hinge axis must be kept low, and for this reason an aileron of small chord is to be preferred.

5. *Additional Measures*

In view of the element of compromise in the solution of the aileron problem we should not neglect to remove characteristics in the aileron control mechanism which depart from those of irreversible control. Chief of these is backlash. All avoidable backlash should be eliminated. Also, in so far as we are unable to eliminate the aileron hinge moments we shall be left with a pure twisting couple on the aileron together with a resultant force acting on the hinge. The flexing and twisting effect of this force on the wing will be less effective the farther is its point of application from the wing-tip. From the point of view of flutter prevention, therefore, an aileron of large span is to be preferred, and this con-

[7] Following Frazer and Duncan, R. & M. 1155.

sideration, taken in conjunction with a previous conclusion regarding small aileron chord leads to the desirability of an aileron of high aspect ratio. Lastly, the effect of the residual twisting couple on the aileron can be reduced if artificial viscous damping of the required order can be applied directly to the aileron.

6. *Conclusions*

We may therefore summarise the conclusions arrived at regarding aileron design for the prevention of flutter as follows, failing irreversible control:—

(*a*) The design of the aileron and the position of the hinge axis should be such that $\partial H/\partial \alpha$ and $\partial H/\partial q$ both vanish simultaneously. It may not be possible to do more than satisfy these conditions approximately; new experimental knowledge appears to be necessary before these requirements can be translated in terms of practical recommendations, but the general indication favours close aerodynamic balance.[8]

(*b*) The C.G. of every section of the aileron should be slightly ahead of the hinge axis. For a " semi-rigid " wing there should be attached to the aileron a mass so placed as to ensure a slightly negative value of the product of inertia of the aileron about the hinge axis and wing root chord.[9] The considerations governing the magnitude and position of the mass will vary with the laws of flexure and torsion of the wing and aileron.

(*c*) The aileron moment of inertia about the hinge axis should be as small as possible consistent with (*b*). Small chord ailerons are, therefore, to be preferred.

(*d*) Span of aileron large, consistent with considerations of general design and possibly the requirements of (*a*); (*c*) and (*d*) indicate that ailerons of high aspect ratio are to be preferred.

(*e*) Elimination of slack in the control gear.

(*f*) Artificial aileron damping.

It is clear that since (*a*), (*b*) and (*c*) represent an attempt to remove the need of irreversible aileron control, measures (1), (2) (previously reached for wing design), (*a*), (*b*) and (*c*) must be taken together for the prevention of wing flutter. If the requirements, on which (*a*), (*b*) and (*c*) have been based, had been met exactly, then (1), (2), (*a*), (*b*) and (*c*) would represent the necessary conditions for the absolute prevention of flutter in the absence of irreversible aileron control. We know, however, that the requirements have been only approximately satisfied and failing irreversible control, flutter cannot therefore be absolutely prevented. We are thus compelled, by immediate practical considerations, to treat the problem as one of postponing the advent of flutter to a sufficiently high speed and any single measure which by itself raises the critical speed is desirable and applicable by itself. Such a measure is the increase of structural stiffnesses; (*e*) and (*f*) fall into the same category. Regarding those other measures where the requirements demand simultaneous application, nothing can be predicted from this analysis as to the effect of applying them other than as a whole. It is possible that the result might be beneficial, but this is a matter ultimately for experiment.

The writer acknowledges the free use he has made of Frazer and Duncan's publications on wing flutter, and assistance he has received from members of the Aerodynamics and Airworthiness Departments of the Royal Aircraft Establishment, Farnborough.

[8] Frazer and Duncan (R. & M. 1155, p. 16) recommend " aileron definitely underbalanced aerodynamically." See also p. 174 for a summary of the theoretical considerations governing the position of the aileron hinge.

Wind tunnel tests indicate that, with mass balanced ailerons, the most favourable position of the hinge axis for the avoidance of flutter is that of close aerodynamic balance. See " Wind Tunnel Tests of Recommendations for Prevention of Wing Flutter," Lockspeiser and Callen, R. & M. 1464, pp. 21-24; also Appendix, p. 31, para. 4.

[9] In the case of a biplane the approximate nodal chord replaces the wing root chord as an axis of reference.

ABSTRACTS AND NOTICES
FROM THE
SCIENTIFIC AND TECHNICAL PRESS

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(Prepared by R.T.P.)

No. 27. JULY, 1933

Aircraft Design, etc.

Vertical Dive in Variable Air Density. (F. Becker, Z.F.M., No. 22, 28/11/32, pp. 659-663.) (306 D.V.L. Report.) (5.10/26001 Germany.)

The motion in a prolonged dive is sensibly modified by the variation in atmospheric density. The modified differential equations are integrable in terms of elementary functions. The atmospheric characteristics are taken as those of the international standard day and a numerical example is worked out.

A graphical chart gives families of curves from which numerical values can be read off.

Limits of Aeroplane Speeds. (E. P. Warner, Aviation, Vol. 31, No. 11, Nov., 1932, pp. 432-433.) (5.13/26002 U.S.A.)

Coefficients of structural and engine weights and of aerodynamical characteristics are taken from the most successful designs.

The possibilities of improving the characteristics are considered in detail and the requirements for speeds up to six hundred miles per hour are plotted graphically.

Without committing himself to prophecy, the author finds that the technical difficulties are very great.

Aeroplane Types Taking Part in the European Circuit, 1932. (W. Pleines, Z.F.M., Vol. 23, No. 19, 14/10/32, pp. 563-577.) (5.14/26003 Germany.)

Forty-three aeroplanes of seventeen different types took part in the competition (sixteen German, no British, two biplanes). In 1930 twenty-nine monoplanes and thirteen biplanes were entered.

The following figures are the average of all the entries:—

Weight empty	=1,000 lb.
Weight full	=1,700 lb.
Weight/sq. ft.	=10 lb./sq. ft.
Weight/h.p.	=12 lb./h.p.

The Adjudication of Marks during the European Circuit, 1932. (Leander, Z.F.M., Vol. 23, No. 19, 14/10/32, pp. 582-588.) (5.14/26004 Germany.)

Sixteen out of twenty-four competitors completed the circuit and received over four hundred marks out of a possible 515 marks under ten headings. The

highest marks were allotted to high cruising speed, followed by equipment, minimum flying speed, regularity, fuel consumption, starting and landing distances. Few marks were given for maximum flying speed, but maximum speeds of about 150 m.p.h. were attained by several competitors in conjunction with minimum speeds of about 40 m.p.h.

Economic Aspects of Transport Aeroplane Design. (R. S. Damon, G. A. Page and K. Perkins, S.A.E. Journal, Vol. 31, No. 6, Dec., 1932, pp. 475-484.) (5.14/26005 U.S.A.)

A lengthy descriptive analysis is given of the factors affecting the economics of design, the list containing 114 headings and sub-headings.

The types of aeroplane are tabulated with details of pay load, power, area and maximum speed with comparative figures of merit varying from 121 to 161, the latter being for an aeroplane with retractable carriage.

Numerous statistical data of costs are tabulated.

Vibration of Aeroplane Instrument Boards. (S. J. Zand. S.A.E. Journal, Vol. 31, No. 5, Nov., 1932, pp. 445-456.) (5.17/26006 U.S.A.)

The design and construction of a three-component vibrograph are described and illustrated by sketches and a photograph. The effect of vibration on calibration is discussed quantitatively.

A table of instruments shows undesirable consequences such as vibration of the indicating pointer, erroneous readings and deterioration. A method of testing shock absorbing qualities of materials for washers, etc., is described and anti-shock mountings are discussed.

The sources of aeroplane vibration are listed and oscillograms are reproduced.

Calculation of Profiles Free from Cavitation. (C. Schmieden, Z.A.M.M., Vol. 12, No. 5, Oct., 1932, pp. 288-310.) (5.20/26007 Germany.)

The methods of conformal transformation are applied to determine the limits of velocity beyond which cavitation sets in. Expressions are employed in Fourier series and the coefficients are determined by the boundary conditions, including the conditions for non-cavitation.

A numerical example is worked out and results are given graphically and in tables for practical ranges of the parameters.

Eight profiles are shown graphically.

Twelve references.

High Lift and Autostability Device in Caudron "Superphalène" monoplane. (L'Aéronautique, No. 163, Dec., 1932, pp. 380-381.) (5.254/26008 France.)

The rear portion of the central wing section is hinged so as to produce variable camber and linked permanently with the tail plane so as to maintain stability. It can also be linked to the ailerons at will so as to produce maximum lift over the whole wing section, while maintaining differential aileron control. The linkages appear complicated. Test figures are given.

Possibility of Increasing Wing Lift. (E. Gruschwitz and O. Schrenk, Z.F.M., Vol. 23, No. 20, 28/10/32, pp. 597-601.) (5.254/26009 Germany.)

Wing flaps were fitted on hinges so that the trailing edge of the closed flap coincided with the trailing edge of the wing. Three flap widths were used, 5, 10 and 20 per cent. of the wing chord.

Drag and moment as functions of lift are shown graphically. The stalling lift is roughly doubled in an extreme case while the corresponding resistance is about four times larger.

Further investigation is required in respect of interference with rudder and aileron control.

Design Formula for Ailerons. (Traitiro Ogawa, Rep. of Aer. Res. Inst., Tokyo, Vol. 7, No. 7, Nov., 1932, pp. 179-194.) (5.30/26010 Japan.)

Approximate formulæ are quoted for the rolling moment imposed by an aileron (W. Schmeidler) and the damping moment (G. Lachmann).

The calculated angle, angular displacement and angular velocity are plotted against time and show close agreement with test results.

A formula is constructed for use of designers and a graphical chart enables values to be read off and at the same time give comparisons with existing designs.

Relevant data are tabulated for over fifty existing aeroplanes.

Pneumatic Tyres. (B. Darrow, S.A.E. Journal, Vol. 31, No. 5, Nov., 1932, pp. 438-444.) (5.50/26011 U.S.A.)

An account is given of the development of pneumatic tyres, with special notice of balloon tyres.

Two types of aeroplane balloon tyres are shown, a 9in. tyre on a 3in. hub and a 15in. tyre on a 6in. hub. The pressure is from 12½lb. per sq. in. as compared with over 50lb. per sq. in. in old style pneumatic tyres.

Aerodynamic Brake. (L'Aéronautique, No. 163, December, 1932, p. 383.) (5.53/26012 France.)

On the Couzinet 100 low wing monoplane the centre sections on either side of the fuselage are hinged and the flaps act as air brakes. Movement of the brake lever first depresses the flaps and then puts on the wheel brake. The aileron control is interconnected with the brake lever and the aerodynamic braking can be increased by the ailerons.

Retractable Undercarriage. (L'Aéronautique, No. 163, Dec., 1932, p. 393.) (5.555/26013 France.)

The wheels of the Blériot 111/5 are retractable to a horizontal position coinciding with the c.g. while the wheel shields act as fairing to the recess.

Airscrews

Take-off and Propeller Thrust. (M. Schrenk, Z.F.M., Vol. 23, No. 21, 14/11/32, pp. 629-638.) D.V.L. Report No. 305. (5.610/26014 Germany.)

The take-off is divided into three sections, taxying, intermediate air-borne state, and lift. The total distance is a minimum when the intermediate portion is flown at maximum lift coefficient. The analysis is illustrated by a numerical example. The agreement with experiments is satisfactory only for taxying. Further data on the variation of airscrew thrust with advance are required.

Design of Airscrews. (D. L. H. Williams, Airc. Eng., Vol. 4, No. 46, Dec., 1932, pp. 310-314.) (5.63/26015 Great Britain.)

A useful summary is given on the elementary principles of aerodynamic theory and design and illustrated by typical characteristic curves.

Applications are made to design for extreme range and to the effects of supercharging the engine and of using variable pitch airscrews.

Formulæ for the Design of Variable Pitch Airscrews. (H. B. Helmbold, Z.F.M., Vol. 23, No. 14, 28/7/32, p. 413.) (5.64/26016 Germany.)

Independent metal blades screwed to a central hub have the advantage over fixed wooden blades of a moderate range of pitch adjustable on the ground. The subsequent discussion shows considerable differences of opinion on the feasible accuracy of setting.

Variable Pitch Airscrew. (Aero Digest, No. 5, Nov., 1932, p. 39.) (5.658/26017 U.S.A.)

A description is given of the " Smith " controllable pitch airscrew with worm gear control giving slow continuous variations at the rate of one degree in two seconds at 1,700 r.p.m. while in operation. The control handle has direct and reverse drive and neutral positions.

Four photographs show details.

Instruments

Measuring Instruments Relying on Electric and Pneumatic Devices and their Employment in Aircraft. (L. Heck, Z.F.M., Vol. 23, No. 14, 28/7/32, p. 416.) (6.0/26018 Germany.)

Electrical devices are suited for measuring deflections and pneumatic devices for measuring forces. The latter may have restoring and operating forces from 100 to 1,000 times greater than the former. Examples of both types are described.

Reference is made to electrical devices for measuring deflection operating on the so-called " quotient " principles (Siemens and G.E.C.).

New Harmonic Analyser. (B. G. Gates, J. Sci. Inst., Vol. 9, No. 12, Dec., 1932, pp. 380-386.) (6.0 (Misc.)/26019 Great Britain.)

Commutator rings in concentric strips are made up in a circular disc with the annular commutator elements separated by annular insulative strips. The inner commutator ring has one contact in its periphery and the succeeding rings have 3, 5, $7-n$ commutator segments (n odd).

The collecting brush of the segment is connected to a valve voltmeter with a reservoir condenser which indicates a voltage expressible as a series in terms of the nth, $3n$th, $5n$th, etc., voltage harmonics, the coefficient, in general, decreasing fairly rapidly. A plate with eight annular commutator rings will analyse the wave up to the 17th harmonic.

The elementary analysis is developed and a numerical example is worked out for a rectangular voltage wave.

Navigation Influence of the Wind in Distance Records. (L'Aéronautique, No. 160, Sept., 1932, pp. 277-279, and No. 162, Nov., 1932, pp. 351-354.) (6.51/26020 France.)

The influence of the wind both on open and closed distance records is considered. A simple apparatus is described for determining the effect of wind on fuel consumption. Examples are worked out.

Hoffman Gyro Vertical Indicator. (Z.F.M., Vol. 23, No. 20, 28/10/32, p. 618.) (6.52/26021 Germany.)

The gyroscope is mounted on roller bearings which stand the conditions on aircraft better than pivot bearings. The drive is by Venturi nozzle.

Power Steering. (P. M. Heldt, Autom. Ind., Vol. 67, No. 24, 10/12/32, pp. 738-743, No. 25, 17/12/32, pp. 774-777.) (6.552/26022 U.S.A.)

The muscular effort demanded by the steering of heavy trucks has led to the design of mechanical drives.

Technical description of several makes is illustrated by sketches and sectional drawings.

In particular a full description is given of the Bosch vacuum control with electro-magnetic control, illustrated by perspective sketch and sectional drawing of the steering column attachment and general arrangement sketch.

Reduction of Platinum Resistance Thermometers. (G. S. Callendar, Phil. Mag., Vol. 14, No. 93, Nov., 1932, pp. 729-742.) (6.71/26023 Great Britain.)

Elementary interpolation formulæ are developed at considerable length for a variety of reductions.

Heat Transfer of Viscous Fluids in Tubes. (H. Kraussold, Forschungsheft, No. 351, 1932—abstracted in Z.V.D.I., Vol. 76, No. 9, 27/2/32, p. 215.) (6.72/26024 Germany.)

The experiments were carried out with warm oil in vertical tubes between 10 and 40 mm. diameter for Reynolds numbers between 20 and 10,000. The results are tabulated in a convenient form for the design of oil coolers. There is fair numerical agreement with a formula given by Prandtl, but the effect of tube length is larger.

In America it appeared that reversal of the direction of heat flow affected the result and this is confirmed and explained.

Evaporation and Heat Transfer at the Surface of a Vertical Plate in Still Air. (R. Hilpert, Forschungsheft, No. 355, July/Aug., 1932.) (6.72/26025 Germany.)

The research is an extension of the work of Lewis, who found (Mech. Eng., Vol. 44, 1922, p. 445) on theoretical grounds that the quotient of the heat transfer coefficients by the evaporation coefficients should be equal to the specific heat of the mixture into which evaporation takes place. The measurements were carried out by noting the loss in weight of clay plates saturated with various liquids. The plates were heated electrically and evaporation was measured in air, hydrogen and CO_2. The results are in approximate agreement with Lewis for the evaporation of water, but a number of hydrocarbons tested exhibited a quotient equal approximately to twice the specific heat of the mixture.

Thirty-three references.

The Prandtl-Taylor Equation. (A. E. Lawrence and J. J. Hogan, Ind. and Eng. Chem., Vol. 24, No. 11, Nov., 1932, pp. 1,318-1,321.) (6.72/26026 U.S.A.)

An empirical equation of heat transfer to water in turbulent motion is given in a form attributed to Prandtl (1910) and Taylor (independently 1916).

Stender's experimental results are reduced to graphical form and lie on a discrete family of unicursal curves. A non-dimensional form places the same results on single unicursal curves. An alternative empirical equation shows smaller scattering of the observed points.

Sixteen references.

Photographs of Caustics Produced by the Temperature Field near a Warm Body. (E. Schmidt, Forschung, Vol. 3, No. 4, July/Aug., 1932, pp. 181-189.) (6.72/26027 Germany.)

Elementary geometrical optical principles are discussed and the formation of caustics is shown graphically.

Refraction takes place in the boundary layer, the depth of which determines the displacement of the caustic curve outwards from the boundary.

Numerous photographs are reproduced and curves show the thickness of the boundary layer for various positions.

Surface Temperature of Bodies of Simple Geometrical Form and Low Thermometric Conductivities. (G. Poschl, Z.A.M.M., Vol. 12, No. 5, Oct., 1932, pp. 280-287.) (6.72/26028 Germany.)

Grober's solutions for plates, spheres and circular cylinders of high conductivity became very slowly convergent for low coefficients of conductivity. His

solutions are therefore transformed into more tractable forms and the computed results are tabulated numerically and plotted graphically.

Seven references.

Aircraft Flight

Longitudinal Stability of Gliders. (M. A. Lapresle, Revue Générale de l'Aéronautique, No. 14, 1932, pp. 105-147.) (7.21/26029 France.)

The model is mounted on gymbals and the pitching moment is balanced against the calibrated moment of a plate.

The restoring couples thus determined are plotted graphically for a variety of dispositions of wings, control surfaces, etc., and conditions for positive restoring couples are determined.

Engines, Thermodynamics

Propagation of Explosion Waves. (D. B. Gawthrop, J. Franklin Inst., Vol. 214, No. 6, Dec., 1932, pp. 647-664.) (8.13/26030 U.S.A.)

A detailed survey is made of methods of photographing rapidly moving particles and waves of expansion sent out by commercial detonators fired electrically.

Twenty-five photographs are reproduced and interpretations are given.

Velocities of explosion waves and of particles of the case are shown for four mixtures, mercury fulminate chlorate, tetryl lead azide, picric acid, mercury fulminate and lead styphnate, the latter of comparatively small intensity.

A table gives results for 12 detonator mixtures. A containing tube increased velocities and effectiveness. The most effective type of mixture is specified.

Nineteen references.

Process of Combustion in Carburettor Engines. (W. Endres, Forschung, Vol. 3, No. 2, March/April, 1932, pp. 78-83.) (8.13/26031 Germany.)

The rate of combustion depends very markedly on the shape of the combustion chamber.

From experimental results empirical curves are established for eight types of combustion chambers and are applied to pre-determination of combustion velocities. Reasonable agreement is shown with experimental results.

Sixteen references.

High Temperature Furnace with Flameless Combustion. (R. Schnabel, Z.V.D.I., Vol. 76, No. 9, 27/2/32, p. 213-214.) (8.13/26032 Germany.)

The high temperatures of flameless combustion are due not only to catalytic effects of porous materials, but also to explosion waves in the hollow spaces.

Interposition of a perforated clay cylinder provides an air space between the crucible and the " contact mass " and increases the effectiveness of the process.

Ionisation During Flameless Combustion Below the Ignition Point. (J. Tausz, H. Gorlacher and H. Draxl, Forschung, Vol. 3, No. 5, Sept./Oct., 1932, pp. 247-251.) (8.13/26033 Germany.)

A fuel was maintained at gradually increasing temperatures in a modified Moore ignition pot. An electroscope was connected to an insulated electrode inserted into the pot and ionisation of the fuel was determined by the rate of loss of charge. Fuels liable to knock produced no measurable ionisation while fuel of high knock rating produced a considerable amount. By adding a dope, iron carbonyl, ionisation was produced in knocking fuels. It is concluded that in all cases ultimate ignition is due to the prior formation of unstable " atomic " combinations, the presence of which produces the observed ionisation. In

" knocking " fuels below the ignition point the unstable products are used up as fast as they are produced and no ionisation is observed. With anti-knock fuel the ionised oxygen is produced faster than it is used up and an ionisation current is observed.

Photographic Methods of Measuring Explosion Velocities. (W. Payman and D. W. Woodhead, Fuel, Vol. 11, No. 12, Dec., 1932, pp. 435-440.) (8.13/26034 Great Britain.)

A description is given of the mechanical details of revolving mirrors and moving films. A small single mirror can be rotated safely up to 500 revs. per sec. giving a speed of image of 500 m. per sec. The speed of a film revolving on a drum is limited by centrifugal forces to the order of 200 m. per sec.

Different systems are shown in eleven diagrammatic sketches.

Twenty-two references.

Internal Energy of Gases after Explosions. (W. T. David, J. R. Brown and A. H. El. Din, Phil. Mag., Vol. 14, No. 93, Nov., 1932, pp. 764-777.) (8.13/26035 Great Britain.)

Comparative tests were carried out in spherical vessels of 6in. dia. and 17.45in. dia., both for fast burning and slow burning mixtures.

The results negative a suggestion put forward that differences of pressures observed in different vessels are due to differences of cooling surface. The explanation put forward here is that incomplete combustion is responsible.

Piston Temperature of a Crossley Solid Injection Engine. (The Engineer, Vol. 154, No. 4015, 23/12/32, p. 644.) (8.14/26036 Great Britain.)

The piston dimensions are 14in. dia. by 30in. overall length, including the crown knob 2½in. dia. by 2in. high. The temperature was measured by 14 distributed thermocouples and varied from max. 650° at the knob, where the combustion is concentrated, to 50°C. at the skirt. It appears that the greater part of the heat is transferred to the jacket through the skirt rings.

Bad Effects of Exhaust Gases. (H. Gorlacher, Autom. Tech. Zeit., No. 20, 25/10/32, p. 495.) (8.15/26037 Germany.)

A summary is given of a report by W. Liesegang. The dangerous concentration of CO ranges from 0.02 per cent. upwards and may be fatal at 0.2 or 0.35 per cent.

Methods of rendering engine exhaust gases innocuous are discussed briefly. Reference is made to a reassuring official report.

Investigating Mixture Distribution. (H. Rabezzana and S. Kalmar, Autom. Eng., Vol. 22, No. 301, Dec., 1932, pp. 587-593.) (8.15/26038 Great Britain.)

Fuel distribution may be measured on a motored engine, but bears little relation to actual performance under running conditions. Exhaust flame colours and sparking voltage contribute further information.

Reliable information can be obtained by means of exhaust gas analysis, provided the exhaust of each cylinder can be analysed separately.

Extensive data collected on these lines are given in tables and charts.

Six photographs show the elaborate equipment required for carrying out tests.

Engines, Design and Performance

Experiences obtained with German Civil Aviation Aero Engines. (B. Bruckmann, Z.F.M., Vol. 23, No. 14, 28/7/32, p. 423.) (8.20/26039 Germany.)

The D.V.L. published statistics of performance of 1,100 civil aviation engines over 700,000 running hours. Ninety per cent. are water-cooled and of these

seventy per cent. are below 500 h.p. All the air-cooled engines are from 500-700 h.p. The average running period between complete overhauls was 180 hours.

Generally, the modern German 6 and 12-cylinder water-cooled engine follows closely the war product of 1918, having practically identical cylinder construction, with modifications in valve seats and crankcase webs.

Since the war English, Continental and American engines have undergone considerable changes in design to meet military requirements and are more compact and lighter.

German civil aviation has a high reputation on the continent, but the question of relative reliability will be settled only if and when equally authoritative statistics such as these become available in other countries. (See Abstract 26040.)

Experiences Gained in the Construction of Aero Engines. (O. Kurtz, Z.F.M., Vol. 23, No. 23, 14/12/32, pp. 691-701, and No. 24, 21/12/32, pp. 721-730.) (8.20/26040 Germany.)

The article deals with constructional features of engines at present employed in German civil aviation and with possible lines of development and is a supplement to D.V.L. Report No. 302 (see Abstract 26039).

Higher flying speeds require a reduction in the air resistance of the engine and a departure from German standard methods of construction. Lack of funds and absence of military orders direct the attention of the German engine builders to development in other countries and lead to the incorporation of the best features in their own designs.

"Universal" Radial Engine. (Aero Digest, No. 5, Nov., 1932, p. 40.) (8.20/26041 U.S.A.)

A brief descriptive account is given of the "Universal" four-cylinder radial engines, showing many novel features of construction. No details are given of the variable pitch control to which brief reference is made.

The Engines used during the European Circuit, 1932. (O. Kurtz, Z.F.M., Vol. 23, No. 19, 14/10/32, pp. 577-581.) (8.225/26042 Germany.)

Particulars are given of the size, weight and method of mounting of ten different makes of light aero engines in 40 aircraft. All were air-cooled and one half had cylinders in line. The average figures for all the engines are:—

H.P.	...	...	135
R.P.M.	...	...	2,130
Lb./h.p.	...	...	2.25

The competition was won by the Polish light aeroplane RWD6, fitted with the English Genet Major engine. Second, third and fourth place and the highest speeds were obtained by planes fitted with the German Argus engines.

Supercharged Aero Engines. (C. Brooks, Airc. Eng., Vol. 4, No. 46, Dec., 1932, pp. 303-309.) (8.235/26043 Great Britain.)

A summary is given with extensive technical detail of the principles of supercharging and controlling the supercharging of engines at different altitudes.

Diagrams obtained with the Farnborough electric indicator are reproduced with curves of power absorbed by the supercharger. A number of mechanical accessories are described with photographs and diagrams, and rules for setting and maintenance are given.

Typical performance figures of supercharged engines are given in tables.

Scavenging Two-stroke Cycle Diesel Engine. (O. P. van Steewen, Autom. Tech. Zeit., No. 19, Oct., 1932, pp. 464-467. See also Werft-Reederei-Hafen, No. 5, 1/3/33, pp. 66-69.) (8.25/26044 Germany.)

The air supply must first scavenge the burnt gases from the cylinder, then refill it with air for combustion and mix with the guttulated (pulverised) fuel.

The paper is largely concerned with accelerating the mixing of air and fuel through turbulence set up by guide vanes.

A large glass cylinder about 1 m. high by 1.7 m. diam. was used to investigate air flow. The air was supplied by a centrifugal fan and sparks from fireworks preparations were used as indicators, the trail of the sparks being recorded on a photographic plate.

It is stated that the time of combustion is reduced to one-fifth or one-sixth by the increased turbulence set up artificially.

Photographs showing spark trails are reproduced and three photographs of three-dimensional models show the result more clearly.

The general layout of the installation is shown in photographs and sectioned sketches give details of valves.

The angular velocities obtained are plotted as nearly linear functions of the r.p.m.

140-*h.p. M.A.N. Diesel for Motor Lorries.* (Autom. Ind., Vol. 67, No. 21, 19/11/32, pp. 647-648.) (8.25/26045 U.S.A.)

Details are given of principal dimensions and performance.

Sketches show the installation in a rail car; a photograph shows the complete engine and a section drawing shows the end view.

The weight of 14.5lbs. per h.p. suggests possible future development for aircraft.

Diesel Bus Test. (J. Geschelin, Autom. Ind., Vol. 67, No. 25, 17/12/32, pp. 771-773.) (8.26/26046 U.S.A.)

Details are given of a 91-hour 3,220-mile run, from New York to Los Angeles.

The engine was a Cummins Diesel six-cylinder ($4\frac{7}{8}$in. by 6in.) rated at 125 h.p. at 1,800 r.p.m.

The consumption was 365 gallons of low grade fuel at 6 cents per gallon.

Thermal and Electrical Theories of Ignition. (J. D. Morgan, Fuel, Vol. 11, No. 12, Dec., 1932, pp. 452-456.) (8.28/26047 Great Britain.)

The results of experimental work on the effectiveness of different types of electrode in promoting spark ignition are reviewed.

The author holds, on the evidence, that heating a sufficient volume of the mixture to explosion point is a process of purely thermal conduction from spark to gas.

The spark energy required depends on the shape and duration of the spark and therefore on the shape of the electrodes. The required energy decreases with increase of spark length and decrease of electrode radius up to feasible limits.

After ignition has been started ionisation takes place and electro-chemical relations must be considered.

Fifteen references.

Electrical Accessories for Aircraft. (W. Brintzinger and B. Bruckmann, Z.F.M., Vol. 23, No. 18, 28/9/32, pp. 541-549.) (8.28/26048 Germany.)

In the new Bosch induction magneto the rotating part carries no windings and has small inertia. Two mechanical interruptors displaced relatively, one of which is shorted, give a large range of timing. With coil ignition reliability depends on the battery. The large increase in weight offsets any small advan-

tages. The high tension cable system with its shield should form a rigid unit capable of installation as a whole.

Modern ceramic materials based on Al_2O_3 combine greater thermal conductivity than mica with satisfactory dielectric properties and make cooler plugs which are urgently needed.

To meet wireless requirements the Bosch shield can be fitted to any plug without serious increase of temperature. Generators should be direct driven by the engine and not wind driven.

Nine references.

The Michel Engine. (S. J. Davies, Engineering, No. 3478, 9/9/32, pp. 290-293; No. 3479, 16/9/32, pp. 333-336; No. 3480, 23/9/32, pp. 353-354.) (8.292/26049 Great Britain.)

This report covers the tests published by Prof. Nagel in Z.V.D.I. (Abstract 24856). (Abstractor's Note.—The high litre performance is due to supercharging and not to suitability for richer mixtures than a normal injection engine. The presentation of the material in both reports unduly stresses the unorthodox mechanical feature in this connection.)

Michel Compression Ignition Engine. (P. Schmaljohann, Autom. Tech. Zeit., Vol. 35, No. 19, 10/10/32, pp. 467-472.) (8.292/26050 Germany.)

Constructional details are given and illustrated by six sectional drawings and three photographs, one of a sectioned engine, one of the engine complete and one of the whole test installation.

Characteristic curves are given of effective piston volume as a function of angular position of crank pin, fuel consumption as a function of speed and power, volumetric efficiency and pressure of pump, and relative contributions of the pistons. (See Abstracts 24856 and 26049.)

Engines, Accessories

Bending Moments in Master Rod of Radial Aircraft Engine. (C. F. Taylor, S.A.E. Journal, Vol. 31, No. 6, Dec., 1932, pp. 488-492.) (8.35/26051 U.S.A.)

A dimensioned sketch of the master rod is given with numerical details specified and a diagram shows the application of these principal forces. Gas pressures are taken from an indicator diagram and the partial and resultant turning moments are shown in elaborate torque diagrams.

Ball versus Tapered Roller Bearings. (J. E. Hamilton, J. Amer. Soc. Nav. Engrs., Vol. 44, No. 4, Nov., 1932, pp. 407-429.) (8.37/26052.)

A comprehensive comparison is made of dimensions and weights for specified bearing loads and end thrusts—between standard ball bearings and tapered roller bearings.

The comparison is in favour of the roller bearing in two-thirds of the cases considered.

Engines, Cooling

Heat Transferred from a Wire to a Transverse Stream. (J. Ulsamer, Forschung, Vol. 3, No. 2, Mar./Apl., 1932, pp. 94-98.) (8.40/26053 Germany.)

By the introduction of four non-dimensional parameters, not all independent, numerous experimental data from various sources are reduced to unicursal curves. Numerical tables and graphical diagrams are given.

Thirteen references.

Research in Heat Transmission. (E. Schmidt, Z.V.D.I., Vol. 76, No. 42, 15/10/32, pp. 1,025-1,032.) (8.40/26054 Germany.)

In the differential equations of heat flow the condition of dynamical similitude suggests parameters of zero dimensions, *e.g.*, Reynolds, Peclet, Prandtl, Grashof and Nusselt numbers.

The representation of results is reduced to a unicursal curve and various analogies are suggested.

Thermal Conductivity of Air Between Co-axial Circular Cylinders. (W. Beckmann, Forschung, Vol. 2, No. 5, May, 1931, pp. 165, 213 and 407.) (8.40/26055 Germany.)

A separation is made of the total transfer of heat measured by subtraction of the part transferred by radiation, as calculated by Stefan's relation, leaving the difference as due to conduction and convection. For dynamic similitude there must be equality of the ratio of diameters and of " Grashof's number," the latter being a non-dimensional parameter involving kinematic viscosity temperature difference, mean absolute temperature and cube of inner diameter.

The results give a family of smooth curves, as functions of these two parameters.

Thermal Conductivity of a Layer of Air between Co-axial Circular Cylinders. (H. Voigt and O. Krischer, Forschung, Vol. 3, No. 6, Nov./Dec., 1932, pp. 303-306.) (8.40/26056 Germany.)

Reference is made to Beckmann's experiments which are substantially repeated and confirmed, with extension to a higher range of temperatures.

Heat Transference by Condensation of Steam in a Vertical Pipe. (M. Jakob, S. Erk and H. Eck, Forschung, Vol. 3, No. 4, July/Aug., 1932, pp. 161-170.) (8.40/26057 Germany.)

In previous experiments the apparatus dealt with 40 kg. per hr., the present apparatus deals with 400 kg. per hr. Full details are given of the mounting of the apparatus.

The results are shown graphically in comparison with Nusselt's formula.

The distributions of temperature and velocity across the pipe show suggestive analogies.

Engines, Lubricants and Lubrication

Lubricating Properties of Oil. (R. O. King, Proc. Roy. Soc., Vol. 139, No. A.838, Feb., 1933, pp. 447-459.) (8.540/26058 Great Britain.)

Measurements of torque resistance of a journal were carried out on a Jakeman apparatus, which provides for the heating of the shaft internally, the temperature being measured by thermo-couple. Nine litres of oil (two gallons) were passed through the bearings in an average time of about $7\frac{1}{2}$ minutes and a stream of air heated to 160°C. was fed into the oil return pipe to promote oxidation. The bearing load was kept constant at 1,000lb. per sq. in. (70 kg./cm.) projected area, or 2,000lb. per sq. in. on projected arc of wear. The measurements were begun when the arc of wear was from 80° to 100° and the bush was scrapped when the arc exceeded 120°. The same oil was passed through the apparatus for $7\frac{1}{2}$ hours per day and for one to two weeks. The whole series of experiments lasted nearly four years. A selection of the tests is given in the form of graphs showing the coefficient of friction against temperature of bearing.

A well defined minimum is reached at a corresponding temperature and is followed by a rise to seizing temperature. The curve is a function of the total running time and a family of curves is obtained which shows marked lowering

of the minimum coefficient of friction to about half and increase of seizing temperature to about double. The lower value recorded is 0.00045.

The beneficial results are attributed to increasing oxidation of the lubricating oil. Molecular theories are suggested on the lines of Hardy's so-called " boundary " lubrication which goes beyond the scope of the experimental data as recorded.

Fuller details in respect of the experimental conditions, in particular accurate measurements of the eccentricity of the shaft, are desirable in considering physical interpretation.

Lubrication. (H. N. Bassett, Autom. Eng., Vol. 22, No. 301, Dec., 1932, pp. 575-6.) (8.540/26059 Great Britain.)

The article deals with " oiliness " and " boundary " lubrication, but no physical definition of either term is attempted.

From the context it appears that " oiliness " is a measure of the bearing loading at which seizing occurs and that " boundary " lubrication denotes the, no doubt, complex, physical conditions prevailing just before lubrication breaks down and the bearing seizes.

A more physical explanation is offered in the suggestion that when roughnesses on both shaft and bearing coincide on a radial line, the lubricating film is pierced locally and direct rubbing occurs between shaft and bush over a small but finite area.

Running in of bearings would smooth such projections by the flow of metal according to Beilby and improve the performance in agreement with experience. Viscosity appears to be confounded with surface tension. Practical devices for postponing the breakdown of lubrication are considered.

Three references.

The Viscosity of Lubricating Oils for High Velocity Gradients in the Film. (S. Kyropoulos, Forschung, Vol. 3, No. 6, Nov./Dec., 1932, pp. 287-296.) (8.540/26060 Germany.)

Rate of shear in bearings may be of the order of 5.5 by 10^4 radians per second, while in viscosimetry it is usually less than 100 radians per second.

A vertical, slightly conical bearing, designed to Prandtl's specification, enables the clearance to be measured accurately and eliminates the complication of eccentricity. Up to 3,000 radians per second the values of μ are consistent with viscosimetric measurements, but at higher rates of shear, with certain lubricating oils, bearing friction may fall as much as 17 per cent. below the calculated value, allowing for temperature effects.

It is remarked that one of the lubricating oils which gives a sensible decrease in observed bearing friction, gives evidence of anisotropy in shear by its relatively high double refraction. This appears to suggest a correlation between molecular orientation and coefficient of viscosity which becomes sensible at rates of shear exceeding 3,000 radians per second.

High Pressure Lubricants. (Autom. Ind., Vol. 67, No. 21, 19/11/32, pp. 650-653.) (8.540/26061 U.S.A.)

An account is given of systematic tests on 16 lubricants. Of the many substances proposed for addition to ordinary lubricants, the most successful are sulphur and chlorine compounds.

It is somewhat obscurely suggested that the chlorine and sulphur liberated at high bearing temperatures combine with the surface metal to form films of iron sulphide or iron chloride which prevent local metallic contact between bearing surfaces.

Details of test apparatus are given, with two photographs and a diagrammatic sketch.

The amount of the additive substance and the viscosity of the mixture is given in a numerical table.

Grouped photographs of experimental journals show the results of running at 200, 400 and 600 r.p.m. The doping of the oil appears to be most effective at the higher speeds.

Contact Effects in Lubrication. (Autom. Tech. Zeit., No. 10, 25/5/32, pp. 258-259.) (8.540/26062 Germany.)

The incipient failure of lubrication is discussed in terms of so-called boundary lubrication with its crude conception of chains of polarised molecules acting as roller bearings.

Bearing Bronzes. (Z.V.D.I., Vol. 76, No. 9, 27/2/32, p. 215.) (8.540/26063 Germany.)

Reference is made to a claim that certain American bearing bronzes absorb oil, in fine pores, up to 40 per cent. of the volume of the metal, without affecting normal lubrication; that the absorbed oil comes into action under overloading; and that a lubricating film is maintained even at low starting torques.

Lubrication Research. (O. Walger, Z.V.D.I., Vol. 76, No. 9, 27/2/32, pp. 205-208.) (8.540/26064 Germany.)

Determinations of friction in a cylindrical bearing with a number of oils under various conditions of load and speed confirm the hydrodynamical theory for a complete oil film of sensible thickness. When surface tension is insufficient to maintain the film the conditions become complicated and obscure until seizing occurs.

Explanations are sought in various physical properties. The transition range between normal lubrication and seizure may be maintained over a considerable range of speed and load. The bearing undergoes a certain amount of wear, suggesting partial or intermittent contact.

The somewhat indeterminate friction torque fluctuates widely and may be heavily affected by the admixture of graphite and other substances. In some cases the minimum observed coefficient of friction lies apparently in the transition range.

Nine references.

Regeneration Method for Used Lubricating Oil. (R. Ascher, Autom. Tech. Zeit., Vol. 35, No. 9, 10/5/32, p. 230.) (See Abst. 25042.) (8.586/26065 Germany.)

During use the oil undergoes oxidation and improves in lubricating quality (oiliness).

Accumulated sludge, acid and foreign matter are detrimental and must be removed. Simple regeneration by filtering through certain clays removes solid impurities and neutralises the free acids. The so-called " crack-smell " (characteristic of used oils) is much reduced. After prolonged use a centrifugal process should precede clay filtration.

Regenerated oils are in every way as good as, and in many respects better than, fresh oils, but their use is restricted by commercial interest in the sale of fresh oil.

Engines, Fuels

Knock Rating Tests in Germany. (O. Enoch, Autom. Tech. Zeit., Vol. 35, No. 8, 25/4/32, pp. 205-207.) (8.645/26066 Germany.)

Four fuels were matched against a benzol petrol mixture by 18 laboratories

using various engines. The matching was done either by ear or by bouncing pin. The results varied by about ±3 per cent. from the average, expressed as per cent. benzol in a benzol petrol mixture supplied as sub-standard. The agreement was satisfactory for general practice, but the discrepancies justify further research. A new standard to replace the expensive octane/heptane is desirable.

" Motor Method " of Determining Anti-knock Values. (C.F.R. Committee, Autom. Ind., Vol. 67, No. 22, 26/11/32, pp. 682-684.) (8.645/26067 U.S.A.)

The intake valve is shrouded to produce turbulence in the entering charge, particularly in the neighbourhood of the bouncing pin. An improved vapour condenser is fitted and the circulating water pump is removed.

The engine speed is increased from 600 r.p.m. to 900 r.p.m.

The testing routine is fully specified and results by the new method show closer agreement with road tests.

Engines, Injection Systems

Guttulation (Atomisation) of Jets in Diesel Engines. (O. Holfelder, Forschung, Vol. 3, No. 5, Sept./Oct., 1932, pp. 229-240.) (8.705/22.2/26068 Germany.)

A full description is given of the experimental installation with dimensioned sketches and tables of 11 types of jet.

Forty-five instantaneous photographs of jets show variety of types breaking up into waves, drops and clouds.

Seventeen references.

The Injection Process of the Diesel Engine. (O. Holfelder, Z.V.D.I., Vol. 76, No. 51, 17/12/32, pp. 1,241-1,244.) (8.705/26069 Germany.)

The distribution of the injected fuel in time and space depends on the fuel pump, the connecting tube and the injection valve. A cylindrical bomb was fitted with windows and shadow photographs were made with short-time spark illuminations of the form of the jet and the ignition lag with open and closed injection valves, needle and pinhole types. The pipe line between pump and valve influences the whole process. The break up of the jet is influenced mainly by the density of the air and this may account for beneficial effects of supercharging.

Three references, thirteen photographs.

Engines, Exhaust Systems

Acoustic Filters as Silencers for Internal Combustion Engines. (A. Kauffman, Autom. Tech. Zeit., Vol. 35, No. 22, 25/11/32, pp. 545-546.) (8.721/26070 Germany.)

Comparative tests were carried out at the Technical High School, Berlin, on a silencer in two sections designed to deal with the high and low frequency sounds in the engine exhaust. The high notes are absorbed by so-called absorption filters, obtained by lining the exhaust pipe with a porous material. The low notes are dealt with by a straight pipe communicating with closed chambers. The straight through passage of the gases produces comparatively little back pressure, while the noise reduction is greater than with baffles.

Silencing Arrangement on Blériot 111/5. (L'Aéronautique, No. 163, Dec., 1932, p. 393.) (8.721/26071 France.)

The heavily ribbed exhaust collector of the Hispano 12 Mor engine projects outside the cowling into the slipstream, following the contour of the nose of the aircraft. The silencer is of the double wall type fitted with external fins and a central passage for cooling air, part of which, when heated, can be deflected to warm the cabin. The pipe connecting the collector and the silencer is also air-cooled. Cooler cylinder heads and substantial reduction of noise are claimed.

Flow through Conical Valves. (L. Richter, Autom. Tech. Zeit., Vol. 35, No. 24, 25/12/32, pp. 591-593.) (8.725/22.2/26072 Germany.)

In reviewing Reports Nos. 50, 51 and 67 of the Aeronautical Research Institute, Tokyo, it is noted that rounding off certain parts of the seating and valve reduced the resistance to steady flow and improved the volumetric efficiency of a Hispano Suiza engine by 3 to 4 per cent. The Curtis D.12 engine has been fitted with chamfered valve seats as standard design.

Engines, Pumps

The Vaudet-Guitant Compressor. (L'Aéronautique, No. 161, Oct., 1932, pp. 321-322.) (8.745/26073 France.)

The blower is of the type in which the rotor is mounted eccentrically on a shaft which is central to the casing. A single vane slides in a radial guide fixed externally to the casing.

Instead of sealing by rubbing contact, under spring pressure, of the end of the vane on the surface of the rotor, a small clearance is maintained by mechanical gearing to the rotor. This eliminates surface friction and allows higher speeds at the price of mechanical complications.

The volumetric delivery of the eccentric rotor type is about half that of the more usual alternative type with rotor mounted centrally on a shaft which is eccentric to the casing.

The eccentricity introduces high inertia stresses and balance is obtained by employing the units in opposition.

Engines, Starting Systems

Use of Tractor for Engine Starting Device. (Aero. Digest, No. 5, Nov., 1932, p. 27.) (8.780/26074 U.S.A.)

A photograph shows a tractor with an attachment improvised out of an old " Ford " transmission for starting an aeroplane engine.

Armament

Smoke Screens Developed by Aircraft. (M. Auriol, Rev. d. F. Aer., No. 41, Dec., 1932, pp. 1,392-1,415.) (9.45/26075 France.)

The application of smoke screens in offensive and defensive has been the object of development work in America and Italy. On land the smoke is produced by stationary apparatus or by smoke shells. At sea, the smoke curtain is produced by the ships themselves. The production of smoke screens by aircraft on land or sea requires accurate co-ordination with land or sea forces. Vapourised chemicals as used for sky writing are too thin. The use of smoke bombs is limited. A coarse spray of liquid tin tetrachloride emitted by the screening aircraft forms a vertical slowly settling screen of a suitable type.

Materials, Characteristics

Nitrided Nickel Steels. (Autom. Ind., Vol. 67, No. 21, 19/11/32, pp. 640-643.) (10.10/26076 U.S.A.)

The addition of nickel to nitrided steel gives marked improvements in tensile strength and yield points, but decreases its elongation and impact resistance.

Specifications of steels and the results of systematic tests are given graphically and in tables.

New Experiments on the Functioning of the Cutting Tool. (F. Schwerd, Z.V.D.I., Vol. 76, No. 52, 24/12/32, pp. 1,257-1,265.) (10.10/26077 Germany.)

A cinematograph record of the shearing of the material at various cutting

speeds shows the periodic blocking of the cutter by the adhesion of the material and the subsequent clearing process. The record is not complete and the value of the partial results justifies further investigation by this method, since the process of plastic deformation underlies all cutting and is of fundamental importance in research on the strength of materials.

Fatigue Strength of Round Struts with Holes Drilled Transversely. (A. Thum and H. Oschatz, Forschung, Vol. 3, No. 2, Mar./Apl., 1932, pp. 87-93.) (10.104/26078 Germany.)

The fatigue strength is unavoidably reduced by transverse drilling, but the effect may be mitigated by several devices, (*a*) cross-drilling to equalise moments of resistance, (*b*) by fitting collars to relieve local concentration of stress, (*c*) by imposing initial stresses round the drilled holes.

The reduction of strength is shown graphically, and an empirical formula is given. A suitable type of collar is shown by photograph and sketch. The resultant stress field (*c*) is shown graphically. A substantial recuperation of lost strength is shown.

Surface Pressure and Fatigue Fractures in Roller Bearings. (R. Mundt, Z.V.D.I., Vol. 76, No. 25, 18/6/32, p. 618, also Forschung, Vol. 3, May/June, 1932, p. 127.) (10.104/26079 Germany.)

Previous attempts to correlate the life of ball and roller bearings with the equations of Hertz had failed. It appears that the important stresses are not the normal surface pressures as assumed by Hertz, but tangential stresses in the direction of rotation. The author has amended the equation and obtained satisfactory agreement with experiment.

Magnet Steels and Permanent Magnets. (K. L. Scott, Bell Tele. B.682.) (10.105/26080 U.S.A.)

The permanent magnetism of a large number of specimens of cobalt, tungsten, chromium and carbon-manganese steels is plotted as a function of parameters such as length of magnet, cross section area, saturation, induction, hardening temperature, etc.

Evershed's criterion taking (*BH*) max. as the controlling parameter is verified experimentally and on this basis an abac (nomogram) is given which determines the highest permanent external magnetic energy per unit volume of magnet steel.

Seven references.

Re-crystallization and Crystal Recovery of Pure Aluminium and Certain Improvable Cu-Al Alloys after Cold Deformation. (H. Bohner and R. Vogel, Z. Metallk., No. 8, Aug., 1932, pp. 169-175.) (10.231/26081 Germany.)

The primary as well as the secondary crystalline structure of aluminium and aluminium alloy rollings, pressings and stampings depends on the temperature, velocity, form and amount of strain, as well as on the temperature of previous and subsequent heat treatment.

Small changes in the original structure, *e.g.*, size and orientation of grains have considerable influence on the final structure.

A chemical analysis is given of four alloys and the elongation is shown as a function of mean size of grains and of temperature of annealing.

Forty-five photographs of grain structures illustrate discussions of the changes produced by various processes and heat treatments.

Much closer control of composition, mechanical processes and heat treatment is required than at present practised in order to maintain a uniformly high standard of mechanical properties.

Twenty-two references.

Mechanical Properties of some Light Alloys. (K. Matthaes, Z. Metallk., No. 8, Aug., 1932, pp. 176-180.) (10.231-2/26082 Germany.)

Chemical specifications are given of six aluminium and two magnesium alloys and the following test results are tabulated for tensile, cubic and shear strains:—

Modulus of elasticity.
Elastic limit.
Ultimate strength.
Strain at point of rupture.
Bending test data and Brinell hardness.

Impact tests and fatigue tests are discussed and test results are shown graphically and in tables. Photographs of eleven fractures of rods are given and one of failure under impact.

Corrosion, fatigue and surface protection are briefly discussed and failure loads are plotted as a function of the number of alternations of stress and the time of exposure to corrosion concurrently.

Five references.

Bending-torsional Tests of Duralumin Tubes. (G. Gabrielli, L'Aerotecnica, Vol. 12, No. 12, Dec., 1932, pp. 1,594-1,605.) (10.231/23.30/26083 Italy.)

The results of combined flexion and torsion failing loads are shown graphically.

Ten photographs show buckled tubes. An application to wing construction is discussed.

Safety Glass. (Autom. Tech. Zeit., No. 20, 25/10/32, pp. 502-504.) (10.406/26084 Germany.)

A single sheet of plate glass is brought to annealing temperature and cooled rapidly so that there are internal stresses in the finished plate. The glass thus treated has higher rupture strength than annealed glass and when ruptured at a point breaks into particles too small to inflict serious injuries.

Internal stress diagrams and strength test diagrams are given.

Three photographs of a ruptured sheet show the nature of the breaking up.

Materials, Defects and Treatment

Internal Stresses in Large Forgings. (G. Kirchberg, Forschungsheft, No. 357, 1932, pp. 1-29.) (10.12/26085 Germany.)

The forgings were circular cylinders, and after forging and heat treatment, successive rings were cut from the forging at different axial positions.

The overall dimensions of the rings before and after cutting were measured accurately.

The rings were then cut radially and further strain measurements were obtained. The mathematical theory of elasticity is applied and appropriate developments are worked out in cylindrical co-ordinates; the results are shown graphically and in tables. The maximum internal stresses were found near the axis.

Twelve references.

Camshaft of Alloy Steels by Electric Furnace. (J. Geschelin, Autom. Ind., Vol. 67, No. 20, 12/11/32, pp. 620-622.) (10.12/26086 U.S.A.)

The chemical composition and test properties of an alloy produced by electric furnace are specified.

The moulds are combined metal and sand with chilling for cam roses and eccentric surfaces. No further heat treatment is required.

Cost, speed and flexibility of design and production are improved.

New Method of Steel Hardening. (O. Gassner, Autom. Tech. Zeit., Vol. 35, No. 22, 25/11/32, pp. 552-553.) (10.12/26087 Germany.)

A new case hardening process—known as the Durapid high speed hardening process—now in operation at several works depends on heating the specimen above its upper transformation temperature and quenching it in a bath at normal temperature with accurate temperature control. Subsequent hardening follows on normal lines. The superior close grain of the steel produced is attributed to the short duration of the high temperature and the elimination of packing boxes and case hardening powders which render the process slow and expensive and productive of warping.

Surface Corrosion. (L. Tronstad, Z. Metallk., No. 8, Aug., 1932, pp. 185-188.) (10.125/26088 Germany.)

The corrosive agent is prepared in the form of a solution with added gelatine to increase the viscosity and with coloured indicators, such as bromocresol purple, bromothymal blue and phenol red to indicate electrical polarity. Copper sulphate solution (5 per cent.) was also used as an indicator and gave well marked yellow colouring to cathodic areas.

A layer is applied to the surface of the metal under investigation and the reactions are studied by microscope.

The indicating colours at anode and cathode are diffused more slowly on account of the increased viscosity and are observable by microscope after the lapse of days.

Bubbles of hydrogen given off at the anode are also held in position. Four micro-photographs of such bubbles are reproduced.

The observations indicate that local anode centres are formed at which hydrogen is given off and cathode centres at which metal is dissolved, with pitting of the surface.

Welded Aircraft Structures. (Autom. Ind., Vol. 67, No. 22, 26/11/32, pp. 669 and 697.) (10.140/26089 U.S.A.)

A summary is given of a paper and discussion at the 33rd meeting of the International Acetylene Association, 16th-18th November.

Prohibition of welds in tension excludes plain butt joint welding.

Exclusion of sea water from tubes by welding sealing plates is essential.

Aluminium and its alloys lose strength after welding and complete cleansing from remnants of welding flux is necessary, while stainless steel loses its corrosion resisting properties.

Chrome molybdenum steel has good welding properties.

Effect of Alcohol Fuels on Aluminium and Aluminium Alloys. (O. Bauer and G. Schikoer, Autom. Tech. Zeit., Vol. 35, No. 24, 25/1/32, pp. 583-589.) (10.262/26090 Germany.)

In view of new laws increasing the obligatory addition of alcohol to petrol fuels experiments were carried out by the official Material Testing Station at Berlin on possible corrosion effects. The corrosion effect was studied by immersing samples of aluminium and its alloys in various types of commercial petrol and benzol fuel containing up to 20 per cent. of alcohol. The corrosion of aluminium tanks and pipe was found to be negligible with as much as ½ per cent. water in the mixtures.

Wind Tunnels

New Methods of Research in Aeronautics—Wilbur Wright Lecture, 1932. (H. E. Wimperis, J. Roy. Aer. Soc., Vol. 36, No. 264, Dec., 1932, pp. 991-1,012.) (11.0/26091 Great Britain.)

The Wright brothers founded their practical success on thousands of experiments on model wings in a 16in. by 16in. wind channel.

The first N.P.L. channel (1910) had a square section, 4ft. by 4ft., while the new R.A.E. channel has a jet of circular section, 20ft. diameter, a motor drive of 2,000 h.p. and a jet velocity of 176 f.p.s.

The great N.A.C.A. channel has a jet of rectangular section, 60ft. by 30ft., and the test chamber is large enough to take a full size aeroplane. The Diesel engine power is 6,500 h.p. and the jet velocity is 169 f.p.s., giving of course a full-scale Reynolds number.

The R.A.E. test chamber is large enough to take the central section of an aeroplane with engine, and can be used for different engine installations, giving the full-scale Reynolds number for the included part of the aeroplane. For wing tests, it is comparatively easy to fit different wings to the same body for comparative tests at full scale, and it is considered that the great additional expense of a wind channel taking a complete aeroplane is not immediately justified.

An alternative method of obtaining a high Reynolds number is the use of compressed air as medium. The pioneer U.S.A. compressed air channel gives a full-scale Reynolds number in a 5ft. diam. jet at 70ft. per sec. wind velocity and 20 atmospheres pressure. The experience thus gained was applied in the design of the N.P.L. compressed air channel which gives nearly twice full-scale Reynolds number with a 6ft. diam. jet at 90ft. per sec. and 25 atmospheres.

The use of water with a density 800 times that of air and much smaller kinematic viscosity has inconveniences arising from the robust supports required by the high pressure with consequent disturbance of the flow.

The field of starting and landing stresses on floats and hulls is explored by means of the R.A.E. tank. When the motion is steady, measurements are accumulated with comparative ease. Unsteady motion, due to waves or to oscillations of the float or hull, lead to much greater difficulties of obtaining and analysing measurements.

The vertical air channel for the investigation of spin has a circular section of 12ft. diam.

The injection of indicators such as the fumes of titanium tetrachloride or filaments of heated air, has much improved the technique of visual observation of flow, and phenomena of fundamental importance are in course of exploration by this powerful means of research.

The suppression of noise is of great importance notably in encouraging air travel. The psychological laws of intensity of sound perception are entirely different from mechanical measurements of intensity. An appropriate scale of intensity of sound perception has to be laid down before the problem of sound reduction can be attacked systematically. The chief sources of noise are airscrew, engine clatter and engine exhaust, and progress in direct reduction of noise from these sources is slow. The alternative method of shielding the passenger in a well-designed cabin has been more successful, and the interior noise has been reduced to the level of intensity in a railway carriage.

Accelerometers are of vital importance in recording the stresses imposed on aeroplanes by external gusts or by aerobatic manœuvres. Under these conditions aeroplane structures tend to become heavier and controls more complicated in defiance of the American precept to " simplificate and add more lightness."

Finally, the objects and achievements of research are " morally neutral." Their direction, beneficial or otherwise, must depend on the character of the users.

The New Göttingen Wind Channel for Airscrew Research. (Z.V.D.I., Vol. 76, No. 52, 24/12/32, p. 1,274.) (11.10/26092 Germany.)

The channel has an octagonal closed circuit 1 m. 85 cm. diameter, with equipment for airscrew research. A motor of 165 h.p. gives speeds up to 120 m./s. Airscrew models up to 50 cm. diameter can be mounted. The density of the air can be reduced.

Tanks, Hydroplanes, etc.

Hydromechanical Problems of Ship Propulsion. (W. Schmidt, Z.V.D.I., Vol. 76, No. 37, 10/9/32, p. 877.) (11.20/26093 Germany.)

Frictional wave and form resistance are considered in terms of modern theory. Particular cases are the Voith-Schneider rotary paddle propeller and ship propeller working in a closed funnel with considerable increase of traction, equivalent in a small tug to an increase in engine power from 120 h.p. to 160 h.p.

Installation for High Speed Towing of Models. (H. M. Weitbrecht, Z.V.D.I., Vol. 76, No. 46, 12/11/32, pp. 1,119-1,122.) (11.20/26094 Germany.)

A full technical description is given of the mechanical and electrical details of a new towing carriage designed to run on the rails alongside the existing tank. The speed has been increased from 8 m./s. to 21 m./s. to meet aeronautical requirements.

Two photographs show the carriage and cable towing gear. A general arrangement sketch shows tank and equipment as a whole.

Experiments with Hydroplanes. (W. Sottorf, Werft-Reederei-Hafen, No. 19, 1/10/32, pp. 286-290, No. 4, 15/2/33, pp. 43-47 and No. 5, 1/3/33, pp. 59-61.) (Reports 106 and 107, Hamburg Shipbuilding Co.) (11.22/26095 Germany.)

In a previous paper a report was made on a systematic research programme and certain fundamental results obtained with a plane surface were given. In the present paper the transformation of results from model to full scale is discussed. The formulæ used for comparison of ships' models with full scale fail for hydroplanes. The boundary layer largely determines the resistance and the type of flow is subject to rapid changes from small models to large models. From large models to full scale the rate of change falls to tractable magnitude.

The results of systematic tests are recorded graphically and in tables for six models over a range of incidences from 0° to 10°. The transition from laminar to turbulent motion is discussed. Moments and resistances are plotted against incidence and velocity. Two photographs show models of different dimensions (4 : 1), towed at corresponding speeds.

In continuation, the influence of keel angle was studied and the shock on impact is shown graphically as a function of keel angle. The shock falls off rather faster than on the D.V.L. assumption, but the friction increases with the wetted surface and spray water is thrown up laterally in greater volume. The gliding ratio and coefficients of moment and aspect ratio of bearing surface are tabulated and shown graphically for a number of tests.

The formation of the sheet of water thrown off is considered hydrodynamically. Measurements of shape were made. Elaborate graphical representations and reductions are used in an attempt to establish systematic relations. Five photographs of the sheet of water are reproduced.

Similar methods are extended to curved surfaces. The geometrical surface curves of five models are given in figured sketches, cœfficients are tabulated and shown graphically. Graphical representations of velocity distribution and spray wave formation are given for curved surfaces and seven photographs of spray wave formations are reproduced.

On the Scale Effect of Aeroplane Model Float Tests. (W. Sottorf, Z.F.M., Vol. 23, No. 24, 28/12/32, pp. 713-719.) (11.22/26096 Germany.)

In aeroplane float tests the reduction of model tests to full scale is difficult. The wetted surface depends both on the speed and incidence, whilst the mean velocity of the water in contact with the float may differ appreciably from the towing speed.

In small scale models the friction cœfficient for the same Reynolds' number depends on the preliminary run conditions and their effect on the boundary layer.

The author carried out experiments both with flat plates and model floats and concludes that the results can only be applied to full scale work if large models are used (scale $\frac{1}{4}$). This applies especially to the point of max. resistance before the float rises on the step.

(It has since been stated by Pabst that model results on the comparatively large scale of the Hamburg tank can be applied without correcting factor.)

Aircraft Components

Tests on Wire Cables. (F. List, Z.V.D.I., Vol. 76, No. 53, 31/12/32, pp. 1,297-1,298.) (11.43/26097 Germany.)

Experiments were carried out on lift cables of various patterns and show the importance of the proper fit of the cable in the pulley.

Airships

Dynamics of the Dirigible. (Revue Générale de l'Aéronautique, No. 14, 1932, pp. 1-103.) (12.30/26098 France.)

A description is given of paradoxical effects of increasing or decreasing the buoyancy of a dirigible.

A discussion of the general problem is based on consideration of the metacentric curves derived from tests on models.

Various ranges are found to exist and the character of dynamical equilibrium changes in passing from one range to another.

A number of problems are worked out graphically and applications are made to analyses of various incidents and accidents in airship operation including the cases of R. 33, the Dixmude and the Shenandoah.

Mission of Naval Airships. (Lt.-Comdr. T. G. W. Settle, U.S. Nav. Inst. Proc., Vol. 58, No. 11, Nov., 1932, pp. 1,621-1,626.) (12.30/26099 U.S.A.)

A favourable view is taken of possible naval application of airships. A descriptive account is given of U.S. equipment with seven photographs showing balloons, kite balloon and shed, small and large airships and aeroplane hooking-on gear.

Air Services—the Akron and Macon. (Aero Digest, Vol. 21, No. 6, Dec., 1932, p. 40.) (12.30/26100 U.S.A.)

The Akron (since destroyed) completed the first year of service with a flying time of 1,131 hours in 51 flights—total distance covered 55,000 miles; total of passengers carried 4,058.

The aeroplane fighter squadron attached to the Akron carried out 401 hook-on operations.

A travelling elevator carrying 1,500lbs. at 175 feet per minute up to 220 feet above the ground will be used for inspection and local repairs of airship hulls.

Economic Airship Construction. (J. Schwengler, Z.F.M., Vol. 23, No. 14, 28/7/32, p. 419.) (12.44-5/26101 Germany.)

The densities of air, helium and hydrogen are in the ratios 1 : 0.14 : 0.07 in round numbers. The use of helium instead of hydrogen involves a loss of 7 per cent. on the gross lift or 35 per cent. on a disposable load taken as 20 per cent. of the gross weight. This is considered a decisive factor against the use of helium in commercial airships, in view of the extreme demands already made on the structural design and materials. Mixed use of hydrogen and helium might reduce fire risks without excessive sacrifice of lift, but preventive methods and careful training of the crew are held to be the effective solution.

With further knowledge of aerodynamical and structural problems the use of helium may become feasible.

Wireless

Frequency Distribution of Atmospheric Noise. (R. K. Potter, Bell Tele. B.697.) (13.1/26102 U.S.A.)

Author's Abstract.—A relation between atmosphere noise intensity and frequency is estimated upon the basis of noise measurement data covering the frequency range between 15 and 60 kilocycles, and 2 and 20 megacycles.

Transformer Coupling Circuits for High-frequency Amplifiers. (A. J. Cristopher, Bell Tele. B.699.) (13.2/26103 U.S.A.)

Characteristics of transformer coupling circuits are discussed and exhibited graphically for five numerical examples.

Transformer circuits show characteristics similar to those of band pass filters and may replace the latter on satisfying certain conditions.

Electro-magnetic Oscillations of Coupled Systems. (M. Stone, J. Franklin Inst., Vol. 214, No. 6, Dec., 1932, pp. 633-646.) (13.2/26104 U.S.A.)

Oscillations of purely electro-magnetic coupled systems lead in general to a system of equations with a symmetrical determinantal eliminant or characteristic.

The author specifies a system in which a prime mover with a centrifugal governor is mechanically coupled to an electro-magnetic generator and load.

This leads to a symmetrical determinantal eliminant. The equations are discussed after Routh's method.

A numerical example is worked out and the ranges of stability are shown for different numerical data.

The term non-unilateral is used by the author to denote the asymmetry of the characteristic determinant.

Kennelly-Heaviside Layer Studies Employing a Rapid Method of Virtual-height Determination. (J. P. Schafer and W. M. Goodall, Bell Tele. B.688.) (13.30/26105 U.S.A.)

From Authors' Abstract.—The virtual height of the ionized regions was determined by visual observations of the received pulse pattern on a cathode ray oscillograph tube, both for single frequencies and for two frequencies simultaneously. A résumé of the data obtained during observations of some three hundred hours is given.

Ten references.

Effects of Topography and Ground on Short-wave Reception. (R. K. Potter and H. T. Friis, Proc. Inst. Rad. Eng., Vol. 20, No. 4, April, 1932, pp. 699-721.) (13.32/26106 U.S.A.)

From Authors' Abstract.—This paper contains some results of an experimental study of the effects which ground and ground irregularities have upon short-wave signal reception. The results illustrate the signal strength advantage to be gained in the selection of suitable ground or topographical conditions and show the influence of antenna types, and vertical angle of signal arrival upon such an advantage.

The agreement between measurement data and theory seems to justify the application of plane wave optical theory to the calculation of vertical plane directivity of antennæ.

Application of Cathode Ray Oscillograph. (R. R. Batcher, Proc. Inst. Rad. Eng., Vol. 20, No. 12, Dec., 1932, pp. 1,878-1,891.) (13.5/26107 U.S.A.)

A concise account is given of the elementary characteristics, calibration and use of cathode ray oscillographs.

Electrostatic and electro-magnetic methods of deflection are compared, the latter requiring considerably more power but at low voltage.

Two photographs of commercial apparatus are reproduced.
Twenty-nine references.

Pressure Record by Pentode Valve. (W. D. Oliphant, J. Sci. Inst., Vol. 9, No. 12, Dec., 1932, pp. 386-388.) (13.5/26108 Great Britain.)

A circuit containing a capacity variable under pressure, a triode, oscillator and a valve voltmeter is replaced by a circuit containing capacity and pentode, the latter acting both as oscillator and valve voltmeter.

A diagram of connections is given and the relation between anode current and capacity charge is shown graphically as a straight line along which experimental points lie closely.

Principles of the Light Valve. (T. E. Shea, W. Herriott and W. R. Goehner, Bell Tele. B.675.) (13.5/26109 U.S.A.)

The mechanism of single and double ribbon shutter valves is described and illustrated by sketches and the frequency impedance characteristic is shown graphically with high peaks at resonance between magnetic field and natural period of ribbon. The instantaneous light received is expressible in Fourier series and the total light, by integration, in Bessel and Fourier series.

The amplitudes of fundamental first, second and third harmonics are shown graphically as functions of frequency.

The elastic characteristics of ten metals used for ribbons are given in a table. Applications are discussed and twelve examples of wave distortion produced by overloading are shown graphically.

A description is given of a new type of valve with permanent magnets and high field intensity.

Nine references.

Electrode Structures of Cathode Ray Tubes for Television Reception. (A. B. Du Mont, Proc. Inst. Rad. Eng., Vol. 20, No. 12, Dec., 1932, pp. 1863-1877.) (13.5/26110 U.S.A.)

An essential element of design is a focussing electrode by which the size of the spot on the screen is maintained while the intensity varies.

Seven diagrams show the relation between voltage of accelerating current and focussing electrode voltage, the size of the spot being sketched in for five or six points on the curve.

Rules for design are given and a satisfactory solution is obtained.

Cathode Ray Compass. (W. Ende and M. H. Gloeckner, Z.F.M., Vol. 23, No. 20, 28/10/32, pp. 603-609.) (13.5/6.50/26111 Germany.)

An elementary account is given of the physical principles. The stream of electrons has no sensible inertia in relation to the gravitational field and is affected only by the earth's magnetic field (see Abstract 22536).

Some constructional details are given of the cathode ray tube produced in the laboratories of the A.E.G. A photograph shows the tube as mounted with contacts, connections and compass rose exposed to view.

Small angular movements of the compass give deflections which depend on its mean orientation in the earth's magnetic field and systematic interpretation of the varying indications is discussed. Calibration curves are shown before and after flight with maximum deviations of about 3 or 4 degrees.

The influence of proximity to the magneto is discussed and the deflection of the ray is shown as a function of distance and of thickness of magnetic shielding.

A test calibration is shown in comparison with that of a magnetic compass, the errors being of much the same general order.

Locating Radio Beacon Stations. (H. C. Stark, Aero Digest, Vol. 21, No. 6, Dec., 1932, p. 39.) (13.6/26112 U.S.A.)

The author, who is instructor in instrument flying for an air transport company, gives a routine for locating an aerodrome beacon and landing in a fog. On p. 38 a map shows chains of beacons in U.S.A.

There are two continuous trans-continental routes and a third is under construction.

Technique of the Sound Film. (H. Kotte, Z.V.D.I., Vol. 76, No. 23, 4/6/32, pp. 545-550.) (13.7/26113 Germany.)

Methods of sound reproduction are discussed concisely. Progress in research and development in Germany have successfully met American film competition and built up an export business. Dialogues in different languages can be synchronised with the same film.

Vacuum Tube and Photoelectric Tube Developments for Sound Picture Systems. (M. J. Kelly, Bell Tele. B.694.) (13.7/26114 U.S.A.)

From Author's Abstract.—An indirectly heated cathode triode is described which makes it possible to use an a.c. supply in amplifiers having flat frequency characteristics with over-all gains of the order of 100 decibels. A measuring system for evaluating the microphonic noise currents is described and the characteristics of a filamentary cathode tube of low microphonic noise level are given. The characteristics of a double anode, thermionic, gas-filled, rectifier tube for use in a d.c. power supply unit for the sound lamp and vacuum tube filaments of reproducing systems are given. A photoelectric cell of high sensitivity for use in sound reproduction work is described.

Photoelectric Cells. (N. R. Campbell, J. Sci. Inst., Vol. 9, No. 12, Dec., 1932, pp. 369-373.) (13.7/26115 Great Britain.)

A lucid exposition is given of the physical elements as a preliminary to discussion of applications in the light of recent improvements in technical detail.

Rectifier cells have usually cuprous oxide or selenium as the element sensitive to light and have the qualities of high emission, cheapness and robustness.

Their constitution is illustrated by a sketch and an equivalent circuit diagram and their current voltage characteristic is shown graphically.

Emission cells produced by the reaction of cæsium with oxidised silver are the most sensitive known and approach the gas filled cell which they will probably displace.

The emission curve is very similar to the visibility curve and the agreement may be brought closer by the use of suitable filters, preferably solutions, to admit of adjustment to variations in the emission curves of different cells.

Conductive cells are excluded from uses requiring exact synchronisation by hysteresis but where a time lag is unimportant they offer the simplest solution of photoelectric control requirement.

Twelve references.

The Caesium-oxygen-silver Photoelectric Cell. (C. H. Prescott, and M. J. Kelly, Bell Tele. B.681.) (13.7/26116 U.S.A.)

From Authors' Abstract.—Technique is described of forming cæsium-oxygen-silver photoelectric cells under controlled conditions. The essential conditions are a quantitative control of the degree of oxidation of the silver cathode base and the amount of cæsium generated, together with a regulation of the amount of chemical interaction by a control of the time and temperature of the heat treatment.

The active surface of the cathode appears to be a film of free cæsium of atomic dimensions absorbed upon a matrix of cæsium oxide and silver containing

free cæsium and a small amount of silver oxide. The spectral characteristics of the photoelectric response appear to depend largely upon the thickness of the surface film of free cæsium. This film thickness is determined by the cæsium concentration in the underlying matrix and is maintained by a diffusion equilibrium.

Twelve references.

Application of Selenium Cells to Physical Measurement. (L. Bergman, Phys. Zeit., Vol. 33, No. 21, 1/11/32, pp. 824-826.) (13.7/26117 Germany.)

The difficulty arising from variation in the light source is overcome by splitting the beam into two parts by partial reflection from a glass plate set at 4°.

One of the beams is reflected by the moving mirror of an instrument and illuminates an area of the photo cell, proportional to the rotation of the mirror.

The other beam is reflected by a mirror rotatable by a micrometer screw, and falls on a second photo cell. An iris diagram controls the intensity of the second beam.

The two photoelectric effects are calibrated so that equal deflections of the instrument mirror and of the controllable mirror produce equal e.m.f's, which are opposed to a galvanometer circuit.

In this way the method becomes a null method and is independent of variations in the original light source.

Interference in Motor Car Receivers. (L. F. Curtis, Proc. Inst. Rad. Eng., Vol. 20, No. 4, April, 1932, pp. 674-688.) (13.9/26118 U.S.A.)

Sources of interference are the sparking plugs, distributor, interruptor and collecting brushes.

Their relative importance is discussed and methods of shielding are recommended.

Six references.

Photography

Photographic Apparatus for Recording the Profile of Model Airscrews. (Z.V.D.I., Vol. 76, No. 51, 17/12/32, p. 1,255.) (14.0/26119 Germany.)

Reference is made to part 4 of the " Aerodynamic Research publications of Göttingen " in which Muttray describes a special camera.

A new apparatus is being developed for photographing wing profiles in a similar manner.

Photogrammetric Equipment of " Graf Zeppelin." (O. v. Gruber, Bildmessung und Luftbildwesen, No. 6, 1931, p. 146—see Z. Instrum., No. 12, Dec., 1932, p. 557.) (14.40/26120 Germany.)

A hand surveying camera with films 18 by 13 cm. and a double series camera with films 13.5 by 12 cm. were provided.

Problems of fixing the orientation and reducing to a common network are discussed.

External Craft Location

A New Stroboscopic Radio-compass for Blind Flying. (R. Hardy, L'Aeron., No. 161, Oct., 1932, pp. 309-315.) (15.05/26121 France.)

The receiving installation has a rectangular rotating frame aerial, a fixed aerial and a 7 valve amplifier. The tuning is recorded by means of Neon tubes either rotating with the frame aerial or driven by a synchronous motor. In the latter case several recorders can be installed in the cabin and the rotating aerial can be housed in the tail. The commutator brush of the rotating aerial and the device for synchronising lamps and aerial are of interest.

Seventeen illustrations.

Sound, Noise Reduction, etc.

Distribution of Sound Intensity. (N. W. McLachlan, Phil. Mag., Vol. 14, No. 93, Nov., 1932, pp. 747-758.) (15.20/26122 Great Britain.)

Expressions in Legendre functions are obtained for the distribution of sound intensity at a distance from various distributions of sound sources on spheres. Numerical results are given in tables and graphically.

Applications are made to hornless loud speakers.

Measurement of Noises. (J. Geschelin, Autom. Ind., Vol. 67, No. 22, 26/11/32, pp. 676-681.) (15.3/26123 U.S.A.)

An elementary account is given of sources of sound, methods of analysis and instrumental equipment.

Two photographs of a three dimensional model show intensity as a function of engine speed and of frequency. As the engine speed rises a chain of peaks spreads upward along the frequency ordinates.

Of some ten peaks only one was found to indicate resonance with natural periods in the car and its suppression met practical requirements.

Seven references.

Interception of Sound Waves by Partition Walls. (R. Berger, Forschung, Vol. 3, No. 4, July/Aug., 1932, pp. 193-202.) (15.38/26124 Germany.)

The material, density and sand or water loading of 16 experimental plates of 4 sq. metres and 13 plates of 1 sq. metre are specified in tabular form. The details of the mounting of an experimental plate and its position separating two closed chambers are shown to scale in four sketches.

The results are collected in 18 graphical charts and include the effects of resonance and of the size and distribution of orifices in the partition.

Elementary physical relations are stated and simplified expressions suffice for comparison of the results of different experimenters.

(The use of a variety of inconsistent units from different international sources is confusing.)

Accidents and Precautions

Safety Explosives in Mines. (Z.V.D.I., Vol. 76, No. 53, 31/12/32, p. 1,294.) (16.05/26125 Germany.)

The range of safe applications of explosives in mines is considerably widened by preventing the ejection of burning fragments of explosive from bore holes, which may produce explosions in gaseous mixtures.

Aircraft, Unorthodox

Autogiro. (Aero Digest, No. 5, Nov., 1932, p. 56.) (17.05/26126 U.S.A.)

A brief specification is given of a Pitcairn autogiro P.A.19.

A photograph shows details of interest—closed cabin, streamlined pylon, engine ring and wings of appreciable area (30½ft. span).

The Clinogyro. (L'Aéron., No. 160, Sept., 1932, pp. 274-276.) (17.05/26127 France.)

The rotating wings are not hinged at the centre as in the autogiro, but oscillate as a whole about the axis of rotation. The device is covered by patents. A full-scale " clinogyro " has been built with rotating wings of 18-foot span, speed of rotation 400 r.p.m., lowest flying speed 30 m.p.h. It is stated that successful flights have been made.

Tail-less Aeroplanes. (A. Lippisch, Z.F.M., Vol. 23, No. 22, 28/11/32, pp. 653-658.) (17.30/26128 Germany.)

A diagram shows three plan forms of wings with wing tips forward of the centre section (sweep forward), in line with the centre section and aft of the centre section (sweep back). In parallel columns are shown the distributions of lift imposed by considerations of stability.

A wing profile with stationary centre of pressure is desirable, but has the disadvantage of negative loadings on the swept back wing tips, which are hinged and used for pitching and rolling control. The flaps must accordingly have balanced moments.

Göttingen profile No. 716 was found suitable and the polar curves are given for three different flap positions. The polar characteristic is also given graphically when a slot is formed between wing and flap.

A tail-less aeroplane constructed on the result of this preliminary work is shown in photographs, along with models and sketches of projected large scale aeroplanes.

Reference is made to the Junkers large aeroplanes or " flying wings," as well as to the G.38 (18 tons-24 tons), Jn.52 (5 tons-9 tons), J.48 (1.5 tons-2 tons).

Meteorology

Wire (Telegraph) Communications in Air Transport. (H. H. Nance, Bell Tele. B.680.) (19.10/26129 U.S.A.)

The organisation of U.S.A. telegraphic weather services is based on teletypewriter equipment. A map shows the ground telegraph system for airport service and the radio service. A weather map shows the nature of the information circulated.

Eleven references.

Aircraft Apparatus

Oxygen Face Masks. (Aero Digest, No. 5, Nov., 1932, p. 42.) (19.32/26130 U.S.A.)

A brief descriptive account is given of a face mask, tested in the low temperature chamber at Wright Field. The oxygen stream is diverted by a baffle plate to produce mixing before inhalation.

Rubber pads separate the eyes and goggles from the breathing space to prevent internal fogging.

Seaplanes, Handling Accessories

Flotation Gear. (U.S. Air Services, Vol. 17, No. 11, Nov., 1932, p. 38.) (20.34/26131 U.S.A.)

Low cloud and poor visibility caused six two-seater bombing aeroplanes launched from U.S.S. Lexington, to lose the mother ship. Two aeroplanes landed on an island and four in the sea. Emergency flotation gear and rafts were inflated with CO_2, all eight occupants were rescued and two of the four aeroplanes were salvaged. The two lost aeroplanes sank while being towed, on account of leaks caused by chafing.

Air Rafts. (Aero Digest, No. 5, Nov., 1932, p. 42.) (20.34/26132 U.S.A.)

A brief description is given of a new design of raft with duplicate concentric inflation tubes, either of which may be inflated to the full designed volume from a cylinder of carbon dioxide gas. The raft is canoe shaped and provided with oars and rowlocks. The largest size, designed for four passengers, will carry six or seven, with additional five men holding on to life lines.

Aerodynamics and Hydrodynamics

Experiments with Capillary Jets. (E. Tyler, Phil. Mag., Vol. 14, No. 94, Supplement, Nov., 1932, pp. 849-881.) (22.10/26133 Great Britain.)

The break up of capillary jets into globules is investigated experimentally with a number of different combinations of fluids in the jet and in the surrounding medium.

An attempt is made to generalise Rayleigh's results for an inviscid fluid by adding a non-dimensional empirical factor.

Experimental results are tabulated and plotted and about fifty photographs are reproduced.

Plane Potential Flow of an Inviscid Compressible Fluid. (G. Braun, Ann. d. Phys., Vol. 15, No. 6, Dec., 1932, pp. 645-676.) (22.10/26134 Germany.)

A potential function is assumed and substituted in the equations of state, motion and continuity, yielding a partial differential equation of the second order with variable coefficients containing squares and products of the first order derivatives.

Solutions are classified and a discussion is given of particular solutions given by Prandtl, Taylor, Bateman and others, by assuming special forms of the boundary conditions or by approximations.

In discussing the general problem the methods of the calculus of variations are applied. The variation of a certain double integral is equated to zero. The integrand is expressed in derivatives of the potential function expressed as a sum of two functions and reduced to linearity by suitable approximations.

Particular values of a parameter corresponding to wave lengths in the motion yield particular solutions.

Numerical applications are worked out for flow past a cylinder and the results are given in tables and curves.

Numerical comparisons are made with G. I. Taylor's work and show fair numerical agreement.

The Modification of a Vortex by Dissipation. (G. Serragli, L'Aerotecnica, Vol. 12, No. 10, Oct., 1932, pp. 1,311-1,321.) (22.10/26135 Italy.)

The author finds expression in Bessel functions of zero order for the redistribution of velocity as a function of radial distance from the axis and of time.

Experiments with a rotating cylinder of small diameter in a cylindrical vessel illustrate qualitatively the increase of the radius at which maximum velocity exists.

Two Dimensional Flow of a Compressible Fluid. (L. Poggi, L'Aerotecnica, Vol. 12, No. 12, Dec., 1932, pp. 1,579-1,593.) (22.10/26136 Italy.)

The equation of continuity for a compressible fluid is formed. Rayleigh's method of solution is discussed and a modification is applied to a circular cylinder. The results are compared with Rayleigh's and G. I. Taylor's experimental results.

An application to a Joukowsky profile is suggested.

Flow in Annular Pipes. (Forschung, Vol. 3, No. 5, Sept./Oct., 1932, pp. 258-259.) (22.2/26137 Germany.)

Measurements are given for a pipe of 19 cm. dia. without core and with cores of 1, 3, 5 and 10 cm. dia.

The results are plotted against Reynolds parameter, in comparison with the results of other experimenters.

The question of roughness of walls is discussed as possibly affecting the conditions of dynamic similitude even when they are " commercially smooth."

Empirical Formulæ for Flow in Smooth Pipes. (J. Nikuradse, Forschungsheft, No. 356, Sept./Oct., 1932.) (22.2/26138 Germany.)

A historical summary is given of recent literature. A full technical description is given, with photographs and sectioned drawings, of the elaborate installation set up at the Göttingen laboratory for observation and measurement of flow in pipes. Measurement of the velocity is discussed and a method of reduction by extrapolation up to the wall of the pipe is given, but the results are in contradiction with the equation of hydrodynamics of a viscous fluid. Extensive observed and transformed data are collected in nine tables and shown graphically in numerous diagrams.

The mean velocity curve as a function of radial distance from the walls of the pipe varies with increasing Reynolds number and approaches a limit asymptotically.

The analogy between turbulent motions and the kinetic theory of gases is discussed, and a parameter is introduced as a function of shear forces and radial gradient of mean velocity, which gives considerable unity to the empirical treatment and is closely related to Taylor's coefficient of eddy viscosity.

V. Kármán's and Prandtl's applications of the principles of dynamical similitude are summarised and discussed in reference to various transformations of the form of the experimental results.

The general aim of the methods is the placing of the observed values thus transformed upon unicursal curves of a simple form, in particular on straight lines, by introducing Reynolds number as a parameter in the manner suggested by the particular assumption made.

Pressure Loss in Smooth Straight Pipe. (H. Richter, Z.V.D.I., Vol. 76, No. 52, 24/12/32, pp. 1,269-1,271.) (22.2/26139 Germany.)

Experiments were carried out on commercial brass tubing 20 mm. diameter and 4in. long at Reynolds numbers from 22,000 to 1,200,000. Compressed air at various pressures give more uniform results than water containing dissolved air. The latter affects the viscosity and may introduce complications by its liberation under reduced pressure. The resistance coefficients are applied to the graduation of a straight pipe air meter which possesses the advantages of extreme simplicity for accurate reproduction.

Measurement of Critical Velocity by Pitot Tube. (E. Tyler, Phil. Mag., Vol. 14, No. 94, Supplement, Nov., 1932, pp. 990-1,003.) (22.3/26140 Great Britain.)

The formation of eddies at the nozzle of a pitot produced audible notes. The appearance of the note indicates the breakdown of flow at the critical speed. The pitch of the note determined the frequency of the eddies. A large number of observed values is given graphically and in tables.

Calculation of Wind Stresses in Cylindrical Containers under Wind Pressure. (K. Girkmann, Sitzungberichts des W. Akad, Vol. 141, No. 9/10, 1932, pp. 651-672.) (22.4/26141 Austria.)

The distribution of wind pressure is taken from aerodynamical laboratory results.

The equations of elastic equilibrium are formed and solutions found which satisfy the boundary conditions expressed in Fourier series.

Some numerical results are tabulated.

Seven references.

Rotary Oscillations of a Cylinder in a Viscous Fluid. (H. F. Winny, Phil. Mag., Vol. 14, No. 94, Supplement, Nov., 1932, pp. 1,026-1,032.) (22.45/26142 Great Britain.)

A long circular cylinder was oscillated in nearly harmonic motion with an amplitude of 2.54 cm. and a frequency of 0.2 to 0.5 per sec. The flow was observed by the motion of aluminium powder.

The observed motions lie fairly well on a curve drawn from Kelvin's solution in Bessel functions. A boundary layer is defined by the surface at which the amplitude falls to 1 per cent. of the maximum value, and is of the same order as that given by Blasius for a flat plate.

Boundary Layer Round Airship Model. (H. B. Freeman, N.A.C.A. Report No. 430.) (22.6/26143 U.S.A.)

A 1/40 scale model of the Akron was used, 19.62ft. overall length.

The boundary layer increased from 0.08in. depth at 15in. from the nose of the model to 10in. depth at the tail.

The velocity distribution is plotted for nine stations and various empirical formulæ are fitted to the experimental curves.

The loss of momentum in the boundary layer accounts substantially for the drag. The transition from laminar to turbulent flow is marked by changes in velocity distribution and in rate of change of depth of boundary layer.

Materials, Elasticity and Plasticity

Plastic Strength of Soft Materials. (R. K. Schofield and G. W. S. Blair, Proc. Roy. Soc., Vol. 138, No. A.836, 1/12/32, pp. 707-718.) (23.10/26144 Great Britain.)

Maxwell's time of relaxation is defined mathematically for a viscous fluid, and the conception is generalised for application to a plastic body.

Experiments on baker's dough yielded figures which were reproducible with some accuracy, and these are shown graphically in seven diagrams.

The authors consider that light is thrown on the phenomena of the hardening of metals under mechanical working.

Sixteen references.

Theory of Resonance Dampers. (O. Föppl, Z.A.M.M., Vol. 12, No. 5, Oct., 1932, pp. 257-260.) (23.10/26145 Germany.)

An elementary example is constructed in which the damping term is linear and the solution is obtained in the usual way.

Solid Viscosities of Metals. (K. Sezawa and K. Kubo, Aer. Res. Institute, Tokyo, Report No. 89, Dec., 1932.) (23.10/26146 Japan.)

Dealing first with the experimental part, bending vibrations of strips of various metals and alloys were observed at pressures of one atmosphere, ½ atmosphere and in high vacua (of the order of 1/1,000,000 atm.) with some intermediate pressures.

The test pieces were of 10 mm. by 1 mm. section with a free length of 150 mm. or 180 mm. and a maximum end deflection of 2 mm. to 5 mm. Logarithmic damping was assumed and the coefficients determined by experiment are shown graphically. These curves are all approximately linear and are extrapolated to meet in a point at zero amplitude. The point of intersection is, however, not one of zero damping coefficient, but of the order of half the maximum damping coefficient observed.

This negatives the assumption made in Part I that Young's modulus E, in the simplified equation of bending vibrations can be replaced by $(E + \xi\partial/\partial t)$.

The simplest mathematical hypothesis is that the shearing stress has two additive components, one proportional to the shearing strain and one to the time rate of shearing strain. The general equations formed on this assumption are given in Ibbetson's Elasticity, Chap. X.

In deriving the authors' equation a further linear relation must be assumed connecting hydrostatic pressure with viscous shearing stress, with the introduction of another constant (see Filon and Jessop, Trans. of the Royal Society, Series A, Vol. 223, 1923, p. 95, " stress optical effects in solids strained beyond the elastic limit ") and reductions and further approximations are required.

In view of the general disagreement of a mass of experimental observations with values given by such hypotheses the mathematical part merely provides exercise in the solution of linear differential equations with constant coefficients.

See Abstracts 26147 and 26148.

Effect of End Pressure on Bending Oscillations with Internal Damping. (K. Sezawa, Z.A.M.M., Vol. 12, No. 5, Oct., 1932, pp. 275-279.) (23.10/26147 Germany.)

The equations are formed with a term proportional to rate of shear. The approximate methods of solution are of interest, but the numerical values for the coefficient of viscosity which is assumed to exist can only be regarded as mean values. (See Abstract No. 26146.)

Seven references.

Theory of Visco-Elasticity. (J. H. C. Thompson, Phil. Trans. Roy. Soc., Vol. 231, No. A.703, 13/3/33, pp. 339-407.) (23.10/26148 Great Britain.)

The assumption that resistance to strain is a linear function of rate of strain as well as of strain involves 36 coefficients of rate of strain corresponding to the 36 coefficients of elastic strain. In practice isotropy is assumed and two new coefficients are introduced.

The author gives a historical account of the development of the subject and proceeds to discuss a number of mathematical consequences. In application to isotropic cylinders two strain coefficients and two rate of strain coefficients are assumed.

(Experimental results do not support this assumption. See Abstract 26146.)

Photo-Elasticity. (D. L. Pellett, S.A.E. Journal, Vol. 31, No. 6, Dec., 1932, pp. 469-474.) (23.15/26149 U.S.A.)

Reference is made to the work of Filon and Coker in the development of the physical principles and technical applications.

An interesting example of a celluloid model wing rib is shown in photograph and dimensioned sketch.

A table of stresses is given with a diagram of stress distribution round a triangular bay.

Stress Optical Photographs of Angles and Double Hooks. (L. Kettenacker, Forschung, Vol. 3, No. 2, March/April, 1932, pp. 71-78.) (23.15/26150 Germany.)

Eleven graphical stress fields are drawn from stress optical observations. An empirical formula is constructed which gives useful approximations for a wide range of practical applications.

Sixteen references.

Secondary Bending Stress in Double Channel Sections. (B. v. Schlippe, Z.F.M., Vol. 23, No. 21, 14/11/32, pp. 625-627.) (23.30/26151 Germany.)

The report is an abstract of an extensive series of investigations carried out in Junker's research department.

A test span is shown in photograph and in sketches lettered in accordance with the symbols used in a mathematical investigation.

Approximate formulæ are developed and a numerical example is worked out and is stated to differ from the test result by about 7 per cent.

Elastic Stability. (A. F. Cornock, Phil. Mag., Vol. 14, No. 94, Supplement, Nov., 1932, pp. 881-896.) (23.30/26152 Great Britain.)

A method of calculating crippling loads of struts and whirling speed of shafts from an initial " reasonable " assumption by successive approximations is developed from Picard's method for solving a linear differential equation with coefficients which are functions of the independent variable.

Numerical examples are worked out and a great saving in computation is claimed in comparison with previous methods.

Reference is made to the work of Rayleigh, Southwell and others.

Elastic Oscillations of a Mass Supported by a Cantilever Spring. (M. Rossiger, Ann. d. Phys., Vol. 15, No. 6, Dec., 1932, pp. 735-740.) (23.46/26153 Germany.)

The motion is compounded of the angular and linear velocities superposed. The equations are formed in the usual way and solved for several cases of interest.

Twenty-four references.

Mechanical Vibrations. (B. E. Eisenhour and F. G. Tyzzer, J. Franklin Inst., Vol. 214, No. 6, Dec., 1932, pp. 691-707.) (23.46/26154 U.S.A.)

Elementary equations are formed for the forced vibration of a simple elastic system with and without damping. A sketch shows simple apparatus for measuring the elastic properties of various materials in the form of pads for reducing the mechanical transmission of vibrations.

Numerical tables are given of natural frequencies of 1 in. sheets of various materials in comparison with a helical spring for different loads per unit surface.

Variation of thickness and elastic stiffness with pressure is shown graphically for cork, felt and wood fibre board.

Four references.

Damping of Oscillations by Internal Friction. (G. Bock, Z.A.M.M., Vol. 12, No. 5, Oct., 1932, pp. 261-274.) (23.46/26155 Germany.)

The hysteresis loop is replaced by an ellipse of the same area and approximately the same maximum and minimum diameters.

This substitution renders the differential equations of motion soluble in elementary functions, neglecting the variation in the loop with varying amplitude. Examples are worked out on these lines and resonance curves are plotted with and without damping.

Ten references.

Miscellaneous

Saturation Pressures of Steam. (A. Egerton and G. S. Callendar, Phil. Trans. Roy. Soc., Vol. 231, A.698, 1/12/32, pp. 147-205.) (0/26156 Great Britain.)

The main object of the paper is to compare the properties of steam in motion with determination of steam at rest in equilibrium, with water in a closed vessel. No appreciable differences were found.

Extensive data are given in tables and compared with the results of other workers. It is considered that tables can be constructed in which the condition of thermodynamical consistency is satisfied, and the permissible limits of error are reducible within small limits. The fit of empirical equations is discussed and

the hope is expressed that a physical relation may finally be established, on the lines of Van der Waal's equation. The experimental installation and methods are fully described.

(The use of pounds and inches seems an unnecessary complication in physical tables of international significance.)

Technical Research in Germany—Index of work in hand at Universities and High Schools. (Z.V.D.I., Vol. 76, No. 42, 15/10/32, pp. 998-1,024.) (0/26157 Germany.)

An index of 1,500 entries exhibits the wide range of active research in German Laboratories. An introductory note urges the importance of maintaining outstanding quality in German products if the present difficulties and tariff walls are to be overcome. Quality can only be maintained if the manufacturer is in touch with the latest research developments. The V.D.I. will foster such intercourse by a series of meetings where technical processes can be dicussed.

Sixth International Cold Storage Congress at Buenos Aires. (Z.V.D.I., Vol. 76, No. 53, 31/12/32, p. 1,300.) (0/26158 Germany.)

By inserting conical blocks of solid dry CO_2 in refrigerator chambers the temperature of the chamber is kept between $-10°C.$ and $+8°C.$ For the smallest refrigerator (clear space 100 by 50 by 30 cm.) the consumption is about 20lb. of CO_2 in a fortnight. Carbonic acid gas is manufactured in conjunction with alcohol, which is mixed with petrol to form a " national " fuel.

The Future of Technical Publications. (Z.V.D.I., Vol. 76, No. 53, 31/12/32, p. 1,303.) (0/26159 Germany.)

The engineer should be conversant with recent development. Technical abstracts should be sufficiently full to give useful information. Rigid sub-division is required, each sub-division being edited by an expert in the particular branch of engineering. The research worker would know what has been already done and the high cost would be recovered by elimination of the present overlap.

Unification of Symbols in German Aeronautics. (H. Blenk and G. Mathias, Z.F.M., No. 22, 28/11/32, pp. 663-669.) (0/26160 Germany.)

The principal German sources are collated with British and U.S.A. terminology. The large number of letters with suffixes in the German list is a symptom of the pressure on the letters of the alphabet (including borrowings from German and Greek characters).

There is in general more disagreement than agreement with British and American symbols, the two latter being closely related.

(A sort of " metric slug " is introduced as one kg. mass × local acceleration of gravity. It is of different dimensions from the British " slug " which is a mass of one lb. multiplied by the numerical value of local gravity. The object of both units is no doubt to make rational mechanics easier for engineers.)

REVIEWS

Air Power and War Rights

By J. M. Spaight. Messrs. Longmans, Green and Co. 2nd Edition. Price 25/-

Mr. Spaight has written a very interesting book on a subject of interest to everyone. He possesses the power of holding his reader's attention even when dealing with matter which is essentially rather dry, and the way in which he illustrates his points by describing incidents in the last war adds much clarity to his narrative.

The subject is of vital interest to this country especially as regards bombing from the air and the main question considered in this connection is this: Supposing we were at war with a country within air range of Great Britain, would it be possible by Laws of Air Warfare to restrict bombing to military objectives, or would the bombing be indiscriminate? Mr. Spaight thinks that "the coming of air power means the end of mass slaughter," and "that a belligerent will naturally repay in the same coin which he has received, will be a powerful influence for moderation in air bombardment." "It will simply not pay to bomb the enemy's cities at one's good pleasure."

In considering the influence of International Law on the actions of a belligerent, it is apposite to take the German use of poison gas in the last war. Mr. Spaight himself says, "The prohibition of the use of poison is one of the oldest and most generally admitted rules of warfare." Poison gases were also definitely prohibited by the Declaration of The Hague, 1899, and also by Article 23 (*a*) of the Rules for Land War, The Hague, 1907. Both of which were ratified by Germany. No prohibition could be more conclusive or binding, but these documents were not allowed to stand in the way when they were considered to be in opposition to the interests of Germany. Our own introduction of the use of incendiary bullets against enemy aircraft is another case in point. Can it be said that any such declaration made now will be considered more binding that those made formerly? The answer is that experience shows that no matter how binding an agreement is, that agreement will be broken immediately a belligerent feels it is in his interest to do so.

Mr. Spaight lays considerable stress on the chivalry shown by opposing Air Forces in the last war, and instances cases where pilots returned from enemy territory without launching bombs, the reason being that under conditions of bad visibility it was impossible to distinguish the military objective from the houses of the populace and that they had abstained from considerations of humanity. Apart from the question as to whether this same chivalry may be expected to occur in the next war, I think Mr. Spaight could have found many more instances in which, under such conditions, the bombs were released above any buildings discernible. Under any conditions, supposing that the bombers were attacked in force by enemy fighters while on their way to the objective, and in danger of being overpowered, they will at once get rid of their bombs in order to improve the manœuvring qualities of their aircraft. It would be natural in such a case to try and damage enemy property of any sort rather than deliberately to drop the bombs in open country.

It would seem that the only means open to a belligerent to defend himself from illegal bombing is the right of reprisals and there is no question that in the last war the fear of reprisals did act effectively in many cases to prevent the bombing of the civil population. But the fear of reprisals is conditioned by the

opinion of a belligerent on the capability of his enemy to carry them out. Should he think his opponent's power in this direction to be non-existent or limited, reprisals are no deterrent whatever. I do not think that a belligerent will fear estranging the public opinion of neutrals by illegal bombing especially as the official accounts of the bombing issued by the two opponents will be such that the neutral will have difficulty in ascertaining the facts of the case. It would seem, therefore, that the use of Laws of Air Warfare is simply this, that if they are broken by one belligerent, to give the one the right to do legally under the name of reprisals what the other has previously done illegally.

From the point of view of this country the position is simply that if we were again involved in war our towns and civil population would be bombed indiscriminately unless we were in a position to make the enemy fear our reprisals, hence the bombing aircraft represents our principal defence.

But it is probable that under existing law it would be legal to bomb the whole of London under the pretence that the bombs were actually aimed at military objectives, for no part of London is so far from one of these to be safe from a badly aimed bomb; for instance, military objectives would or might include all railway stations, railways, gas works, electric light works, barracks, government buildings, docks, engineering works, etc., and these, with the personnel at work in them, would be considered legitimate objects of enemy action, and the enemy could not be held responsible if, in attacking such objects, he inadvertently killed women and children. In attacking material of this type obviously high explosive bombs would be used. The use of gas bombs against the personnel of such establishments is again prohibited by the Washington Treaty of the 6th February, 1922 and also by the Geneva Gas Protocol of 1925. The latter also prohibits bacteriological methods of warfare. But whether these documents would be more effective than the pre-war agreements with a similar object is extremely doubtful, unless supported by the fear of reprisals.

It is to be hoped that Mr. Spaight's book will be widely read by the general public who will be the principal sufferers by air action in any future war, and who should understand the risks to which they will be subjected. Those members of the Fighting Forces whose lot it may be to apply the Laws of War will find the work invaluable.

The Air Annual of the British Empire

Vol. V, 1933-34. Published by Sir Isaac Pitman & Sons, Ltd. Price 21/-

The latest edition of the Air Annual is worthy of its predecessors and is a most useful and valuable work. This edition contains special articles on The British Aircraft Industry by H. J. Thomas, on Military Aircraft by Frank C. Cowlin, B.A., on Aeronautical Training in Great Britain by Oliver Stewart, on Air Line Tributaries by Major C. C. Turner, on Imperial Airways by G. C. Woods Humphreys, and on Land, Sea and Air by Wing Commander E. L. Howard Williams, M.C., in addition to a number of others.

The book is specially notable for its very full description of the products of the British Aircraft Industry, comprising, not only the aircraft and engines manufactured by the various firms but also instruments, hangars, airport equipment manufacturers. This section is dealt with very fully and the book is a valuable reference work for all interested in aircraft. The French and Spanish supplements also add to the usefulness of this section when the book is in use abroad.

It is interesting to note the progress of British commercial aviation as demonstrated by the curves and statistics given in the article by Mr. Woods Humphreys. It seems that this company is now operating on a subsidy of 35 per cent. of the total revenue which is probably lower than that of any other European Air Line.

The book forms an invaluable record of the progress of British Aviation and should be in the hands of every one interested in the subject.

Airsense

By W. O. Manning, F.R.Ae.S. Sir Isaac Pitman and Sons, Ltd. Price 3/6 net.

Although, at first glance, there appears to be a plethora of books on aviation, deeper investigation quickly reveals the fact that there are too few books on certain aspects of it and too many on other aspects. The air is coming into its own quickly, almost too quickly in some ways, and many are now beginning to take an active interest in all air matters.

There has long been wanted some book which will explain in simple every-day language how an aeroplane flies and how an aero engine works. Most books fall between two stools, they are too elementary for the man who wishes to delve deeply into the subject and too full of technical terms, assumed known to the man in the street, for the latter to be able to follow the argument.

Mr. Manning steers neatly between the two stools. He has written a book which is exactly the one wanted. His explanations and his analogies are within the comprehension of the non-technician, who will, when he has finished reading Mr. Manning's book, be able to understand much of what the technical expert is driving at. The familiar hum of the telegraph wire enables the mystery of the air vortex to be explained. In explaining why the landing speed largely governs the wing area of an aeroplane, the author points out that landing speeds in America are higher than in England probably because the landing conditions are better. He tells the amusing story of the American pilot flying a fast American aeroplane in England, with a high landing speed, who remarked that if he had engine trouble over England he would " take to the silk," in other words abandon his machine and come down by parachute!

On page 38, Mr. Manning remarks " It is curious that when Nature makes an animal which can support itself in a fluid, either air or water, she finds it necessary to fit only an horizontal tail plane or a vertical tail fin, never both. The two used together are only found in appliances made by man." He explains clearly the reason why and adds, " Hence, it by no means follows that some peculiarity of a bird's wing is necessarily a good thing to imitate in aircraft." The reviewer commends his comment to those who view bird flight from only one angle, how to imitate it. Undoubtedly there has not been a proper study of bird and insect flight, and much will be learnt when a full study is made. But it is certain that some of the appliances of man, the wheel and the airscrew, for example, will always prove more efficient in their respective ways than anything nature has yet produced.

The second half of Mr. Manning's book is devoted to the study of the aero engine and the way it works. He begins with describing why petrol is the most suitable fuel and how its value as a fuel is measured, and the way an aero engine works. The whole section is thoroughly informative and one which should be read by every pilot who is not content merely to be able to fly an aeroplane.

On page 45 appears the following: " Progress is increasing, and in five years' time every engine made to-day will be obsolete, and the same thing will happen to our present aeroplanes." It is to be hoped that Mr. Manning is a true prophet, for in five years' time the air will be at least five times as crowded as it is now and with new engines and new aircraft the lot of the aircraft manufacturers and engine makers should indeed be a happy one.

The 564th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

NINTH MEETING, SECOND HALF, 68TH SESSION

A Meeting of the Royal Aeronautical Society was held on Thursday, April 27th, 1933, at 6.30 p.m., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, when a lecture was delivered on "Seaplane Research," by Mr. H. M. Garner.

In the Chair: Mr. H. E. Wimperis, Director of Scientific Research, Air Ministry.

The CHAIRMAN: Before commencing their proceedings they would no doubt consider it right that he should express the great regret that they all felt at the death of the Chief of the Air Staff, Air Chief Marshal Sir Geoffrey Salmond. Sir Geoffrey was a great friend to the Society, and was known by his name and work, if not personally, to everyone present. To a good many of them he was known exceedingly well. When he was Air Member for Supply and Research, the research organisation with which their lecturer was connected was founded, and had it not been for his insight, energy and sympathy it was doubtful whether that scheme of reorganisation would ever have come to fruition. He had done distinguished work, as they knew, during his career in the Royal Air Force, and had just relinquished the great office of Commander-in-Chief of the Air Defence of Great Britain with a view to taking the still higher one of Chief of the Air Staff and head of the Royal Air Force, under His Majesty the King. Their hearts were very full, and he was sure that he was voicing the views of everyone present, including the whole of the Royal Aeronautical Society, and indeed the Aeronautical Industry of this country, as well as the Royal Air Force itself, in expressing their deep regret at his death.

Turning to the subject of their Meeting, the Chairman said he had known the lecturer for many years. Mr. Garner was a distinguished mathematical student at the University of Cambridge, and at the time when they first met, during the war, was an officer of the Royal Naval Air Service. After that he served at Farnborough for some years, and subsequently became Principal Scientific Officer at the Marine Aircraft Experimental Establishment at Felixstowe. In the minds of a good many people Felixstowe and Martlesham were linked; they were viewed as parallel institutions. From some points of view they were, but there was this difference to be remembered, that whereas at Farnborough experimental work on land machines could be, and was, carried out, one could not there do full-scale research on seaplanes, and that work was left to Felixstowe. Therefore Felixstowe had not merely duties, in respect of seaplanes, comparable with those that Martlesham had in regard to landplanes, but had in addition the research work in seaplanes similar to the full scale at Farnborough for land planes. As a result Mr. Garner's duties as Principal Scientific Officer were many sided, and, if he might be permitted to say so, Mr. Garner had rendered distinguished service in that office.

SEAPLANE RESEARCH

BY

H. M. GARNER

Acknowledgments

I am indebted to the Air Ministry for permission to read this lecture and to give the information contained in it, but I am to point out that the opinions expressed in the lecture are entirely my own.

I have given, as far as I could, reference to original papers. A good deal of the more recent work at the M.A.E.E., however, has not yet been published. Most of it, it is hoped, will be published in due course. I should like to take this opportunity of expressing my appreciation of the work of the small staff at the M.A.E.E., whose efforts have largely made this lecture possible. I should also say that we have received invaluable assistance from the R.A.E., particularly in the detail design, and construction of the larger pieces of apparatus, which were beyond our limited resources.

Introductory

In considering the possible range of this lecture, I decided that it would be better to describe fully the work which is being done on a few of the most important problems, rather than attempt to cover a very wide field more loosely. The aerodynamic aspect for seaplanes is very similar to that for landplanes, which has often been discussed in lectures before this Society, and will not be considered here. No attempt also is made to discuss what may be called seaplane accessories. These are very important and extensive; the work on seaplane anchors alone might provide material for a whole lecture.

In addition to the problems common to all types of aircraft, there are two main problems facing the designer of a seaplane, one hydrodynamical, the other structural. The hydrodynamical problem is to obtain a hull or floats with the following good qualities:—

(*a*) Low resistance.
(*b*) Adequate stability.
(*c*) Seaworthiness, under any reasonable conditions.

The structural problem is to design a hull which shall be as strong as possible for a given expenditure of weight. The two problems are interconnected in a most complicated way, and it may be said, in general, that no one of the hydrodynamical qualities (*a*), (*b*) and (*c*) can be altered without affecting the other two, and that these in turn closely affect the loads on the hull and hence the requisite strength of the structure.

Even if the designer is supplied with complete information on the above points for a number of hulls and floats (and it would take many years of research to supply this information), the design of hull he would adopt would depend upon the relative importance which he attached to the various qualities, and also upon the special purpose for which the seaplane was designed. It is perhaps desirable to point out that great, even violent, differences of opinion are held on this relative importance, and that these differences will probably for many years affect individual design. This question however, is, fortunately for me, outside the range of this particular lecture.

Starting then with the first of the three good qualities laid down as desirable, and it must be definitely stated that the order (*a*), (*b*) and (*c*) is taken for convenience and does not imply any order of priority, it is of great importance that the water resistance of a seaplane shall be as low as possible. A landplane, designed to have a reasonable performance in the air, has no difficulty in taking off in a reasonable distance. A seaplane may have a good performance in the air and yet may not be able to take-off in no wind, even under perfect water conditions. This may be explained by saying that the coefficient of friction of a seaplane on the water is about one-fifth as against one-tenth, or less, for a landplane.

One of the most important problems facing the designer of flying boats to-day is the design of a practical flying boat with the longest possible range. It may be said that a range of 2,000 miles is just possible on a flying boat weighing, say, 15 to 20 tons and carrying a small pay or military load. For some purposes this range is adequate, but for others, such as a trans-Atlantic service, a still longer range is required. Although I realise that still higher aerodynamic and engine thermal efficiencies than the present ones are necessary, I think I am right in saying that the greatest obstacle to obtaining longer ranges is the high water resistance during take-offs.

I shall now describe the research work which is at present being done on this most important problem, and the way in which this work is likely to develop in the future.

Measurement of Water Resistance of Hulls and Floats

For many years the standard procedure for determining the water resistance of hulls and floats has been to deduce the resistance from that of models tested in a water tank. It has been assumed that the resistance is very largely wave-making resistance, and the model tests have therefore been made at the same Froude's number (v^2/l) as that on the full-scale seaplane. The full-scale resistance has been deduced from the model resistance by using Froude's Law, no correction being made for skin friction resistance.

In the last few years doubts have been expressed as to whether this method is sound, particularly at speeds near to the take-off speed. It is argued that displacements at these high speeds are small and that most of the resistance is frictional. If this contention is correct, the methods previously adopted for determining the full-scale resistance are unsound and large errors in the value for the resistance may be obtained.

The necessity for making tests on larger models at higher speeds in order to settle this point seems to have been realised almost at the same time in England, the United States, and Germany. In England two tanks, one at the R.A.E. and the other at the N.P.L., with maximum speeds of about 40 ft./sec. and 30 ft./sec. respectively, as compared with the previous highest speed in this country of 25 ft./sec., have recently been designed and are now working. In Germany a high-speed tank has been erected at Hamburg (Ref. 1) and a high-speed carriage has been designed for the small Berlin tank (Ref. 2). All these tanks are small compared with the N.A.C.A. tank at Washington (Refs. 3 and 4). The length of this tank is 2,020 ft., its breadth is 24 ft., its depth 12 ft., and speeds of 88 ft./sec. can be obtained. The resistance of a full-scale float of a seaplane weighing about 6,000 lbs. can be measured in this tank at a speed equal to the full-scale take-off speed.

Let us consider for a moment the fundamental quantities involved in the attempt to correlate the resistance of a full-scale hull with the model resistance. I shall take a flying boat such as " Singapore II," weighing about 30,000 lbs., with a hull about 50 ft. long and a landing speed of about 100 ft./sec. The size

of model which can be tested in the tank is limited by the breadth and depth of the tank, because the interference must not be too large, and by the maximum speed attainable.

The effect of the interference of the walls and bottom of a tank on the resistance of large model hulls has not yet been fully investigated. Some evidence has recently been produced, however, which suggests that the interference on a model whose length is about equal to the width of the tank is important. Tests were made on the same model in two tanks, whose widths were 1.8 and 9.5 times the length of the model. The resistances measured at a constant displacement over the whole speed range are shown in Fig. 1, and at a displacement diminishing with speed, such as occurs during a take-off run, in Fig. 2. In both figures the

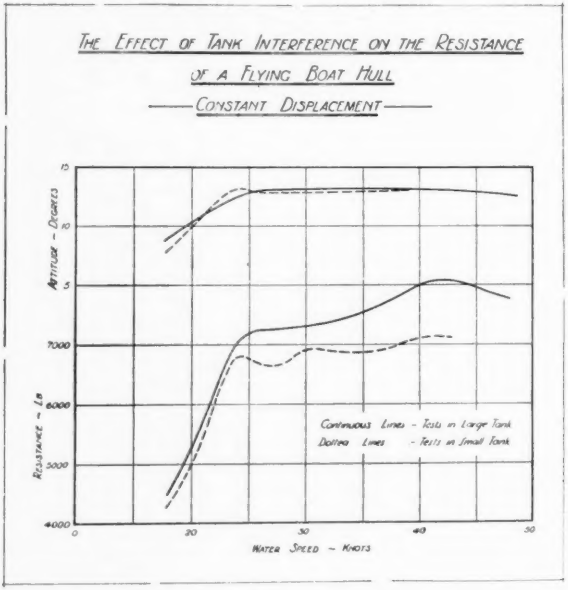

FIG. 1.

natural attitudes taken up during the tests are also given. The attitudes agree very well for the two tanks, but the resistance of the hull in the small tank is on the average nearly 10 per cent. less than in the large tank. The problem is of importance in connection with the new R.A.E. tank, whose cross section is small (9 ft. × 5 ft.), and the problem is being further investigated there.

Quite apart, however, from the effect of the tank boundaries on the resistance, the maximum speed attainable in the tank limits the size of the model which can be tested. The value of Froude's number for the model at its highest speed must agree with that of the full-scale hull at or near to the take-off speed. It can easily be shown that the largest model which can be tested in either of the high-speed tanks in this country is about one-seventh scale. The value of vl for this model is less than one-twentieth of the full-scale value.

Now if a large part of the resistance is skin frictional, and if, in addition, there is an appreciable scale effect on that part, as appears very possible in a change of Reynolds' number to twenty times the model value, the results of tests on models one-seventh full-scale may be misleading. The N.A.C.A. tank could take a two-thirds scale model of the " Singapore II," and the value of Reynolds' number would be half the full-scale value. We are then, possibly, in this respect, at a considerable disadvantage compared with the United States.

Fortunately, however, apparatus has been designed, both in this country and in Germany, by which the resistance of full-scale seaplane floats can be measured over the whole speed range. In this country, further, the scheme has been extended to apply to a large-scale model of a flying boat hull. Thus the large

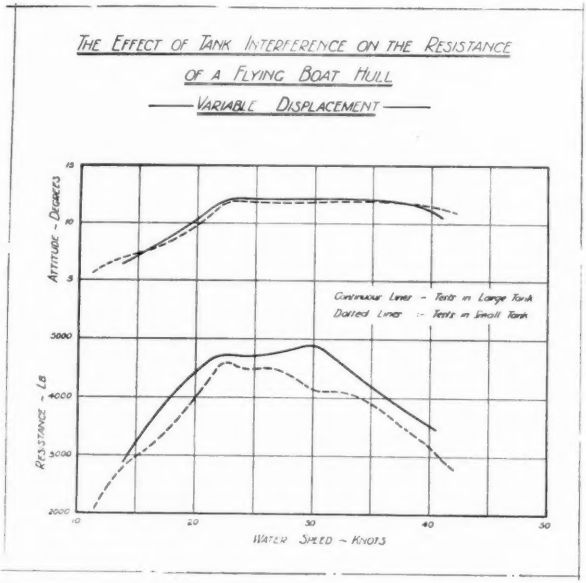

FIG. 2.

gap at present existing between full-scale and model is bridged, and the scheme, in effect, takes the place of a large tank.

M.A.E.E. Scheme of Measurement of Resistance

The M.A.E.E. scheme, applied to a " Fairey 111F " twin-float seaplane, is shown diagrammatically in Fig. 3. The float is supported from the fuselage by parallel struts AB, CD, freely hinged at their ends. A pyramid of struts is built up from the floats and the apex of the pyramid is attached to one end of a spring E, the other end of which is attached to the fuselage. Thus the water resistance of the floats is balanced by the load in the spring and is measured by its deformation. The deformation is recorded by a control movement recorder. The hinges at A,B,C and D are of the elastic distortion type.

The scheme was first applied at Felixstowe to a standard 111F twin-float seaplane. The aircraft and apparatus are shown in Fig. 4. The measurements

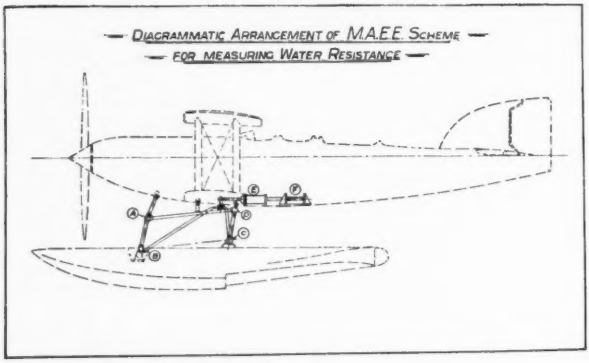

Fig. 3.

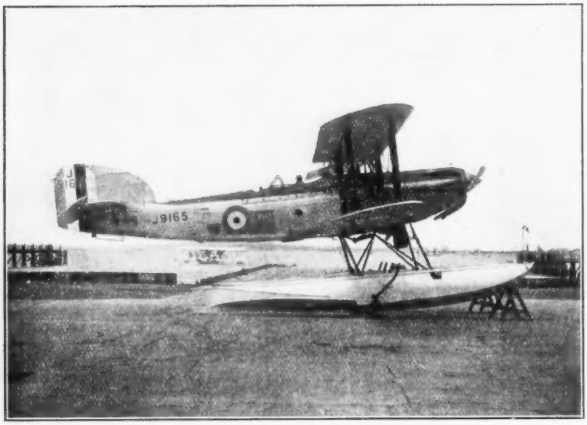

Fig. 4.

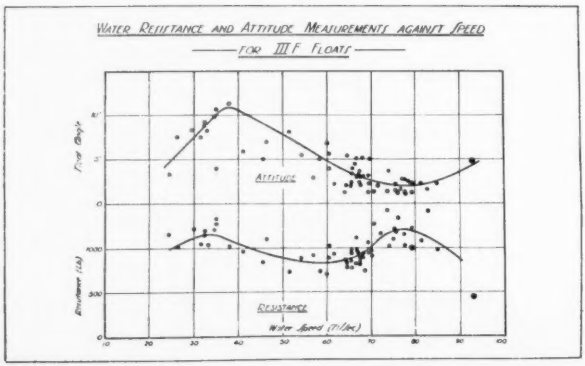

Fig. 5.

of resistance, which may fairly claim to be the first complete full-scale measurements of this kind, plotted against the speed, are shown in Fig. 5. In the same figure the attitude, which was determined by a gyro recorder, is also shown; in Fig. 6 the resistance points have been corrected to a constant attitude at each speed. The accuracy of the results may be judged from the scattering of the observations: it may be said that the standard of accuracy is almost up to

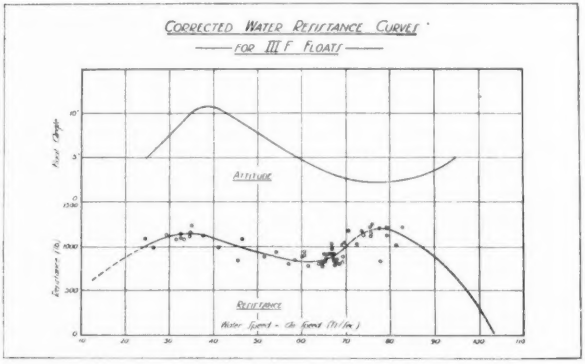

FIG. 6.

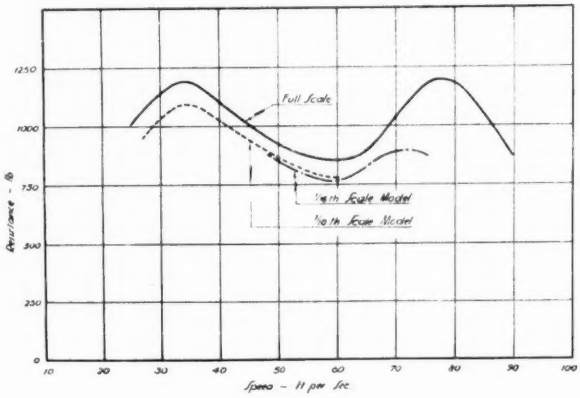

FIG. 7.

that of other full-scale work—a very satisfactory achievement for tests with a new type of apparatus. In Fig. 7 the full-scale resistance is compared with the resistances of a one-tenth scale and a one-sixteenth scale model, the comparisons being made at the full-scale attitude. The full-scale resistance is about 10 per cent. higher than that of the one-tenth scale model over the whole range.

An account of the full-scale measurements, which were made by E. T. Jones, is given in an unpublished report (Ref. 5).

D.V.L. Scheme of Measurement of Resistance

A scheme working on the same principle, but quite different in detail, has been evolved in Germany by the D.V.L. In this scheme the vertical forces on the float at two points, as well as the horizontal force, are determined. The scheme in its first form as described by Seewald (Ref. 6) was, I believe, not entirely satisfactory and was not tested. An improved design followed, of the form represented diagrammatically in Fig. 8, which has proved to be very satisfactory. The vertical force at A is balanced, through the lever arm A,B,C, by a vertical force at C, which is supported by the oil pressure inside a dash pot

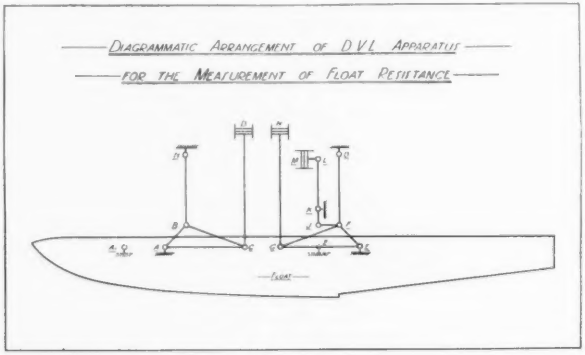

FIG. 8.

at D. Similarly, the vertical force at E is supported by the pressure in the dash pot at H. The horizontal force is measured, through the lever J,K,L, by the dash pot M, the float being free to move horizontally on the parallel motion linkage N,B,O,F. Alternative points of support A′ E′ are provided on the float.

Apparatus based on this design, fitted to a " Junkers F.12," was in continual use on the Boden See during the summer of 1932, and a large number of measurements were made. By the courtesy of Professor Hoff, of the D.V.L., I was able to take part in some of the tests of the apparatus, and was very impressed by the thoroughness and care devoted to the work. I am not at liberty at present to give further particulars of the apparatus, which, with an account of the results obtained, is to be described in a D.V.L. Report later on.

Application of M.A.E.E. Scheme to Large Models

The next stage in the attack on the resistance problem is to apply the scheme to a model of a large flying boat hull. The application of the scheme requires a number of conditions to be satisfied. In the first place, the displacement of the aircraft to which the model hull is attached must satisfy the relation

$$\Delta_1/l_1^3 = \Delta_2/l_2^3 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where Δ_1, Δ_2 are the displacements of the full-scale flying boat and model-carrier respectively, and l_1, l_2 are the linear dimensions of the full-scale and model

hulls. In the second place the take-off speeds v_1 and v_2 must satisfy the relation

$$v_1^2/l_1 = v_2^2/l_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in order to make the Froude's numbers at take-off speeds agree. If this condition is satisfied, and the lift curves of the two aircraft have the same characteristics, it is possible to find for every speed on the full-scale aircraft a speed on the model which is a true *corresponding speed.*

The two conditions that the model hull must satisfy, impose a necessary condition on the model-carrier. This condition is

$$\Delta_1/\Delta_2 = v_1^6/v_2^6 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

thus the weight of the model-carrier must be proportional to the sixth power of its stalling speed.

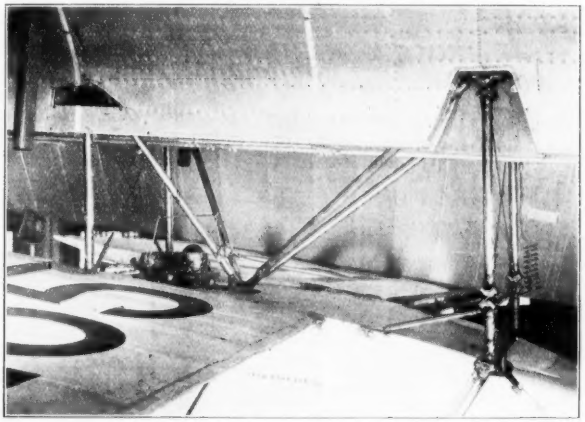

FIG. 9.

For the tests of the " Singapore II " model hull a " Moth " was chosen as the model-carrier, mainly in order to keep the cost of the experiment as low as possible. Unfortunately, the stalling speed of the standard " Moth " was too high for the above condition (3) to be satisfied, and larger wings were therefore necessary. The scale of the model is decided by equation (1) and is found to be about 1/2.3. Thus the value of lv for this experiment is about 1/3.5 times the full-scale value. This should be sufficiently near to the full-scale value for the Reynolds' number scale effect to be small.

The apparatus for these experiments includes, in addition to the resistance-measuring dynamometer, two dynamometers measuring the lift on the float at two points. The apparatus is shown diagrammatically in Fig. 9, and a photograph of the " Moth " with the resistance apparatus only fitted is shown in Fig. 10. The measuring apparatus is partly concealed in the fuselage, and the " Moth " does not differ much in external appearance from an ordinary seaplane.

Up to the present we have not obtained a great deal of information on the " Singapore II " model. We have, however, obtained a preliminary determination of the resistance over the lower part of the speed range. It is shown compared with the resistance of a one-sixteenth scale model in Fig. 11.

A comparison of the British and German types of apparatus for this experiment shows great differences in detail, although the general principles of

design are the same. The main difference is the use of spring dynamometers with comparatively large movements (of the order of one inch) in the British apparatus, as against hydraulic dynamometers by the Germans with much smaller movements (about 1/100 inch).

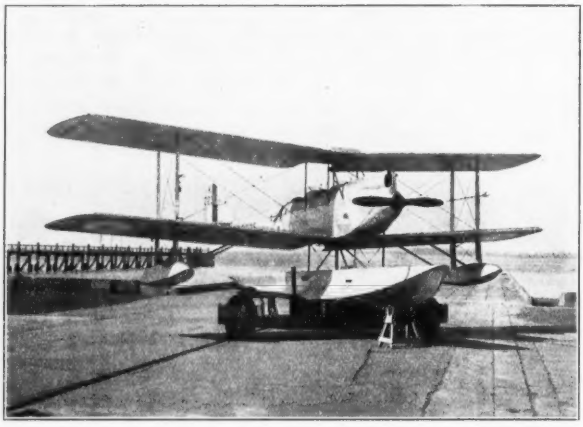

FIG. 10.

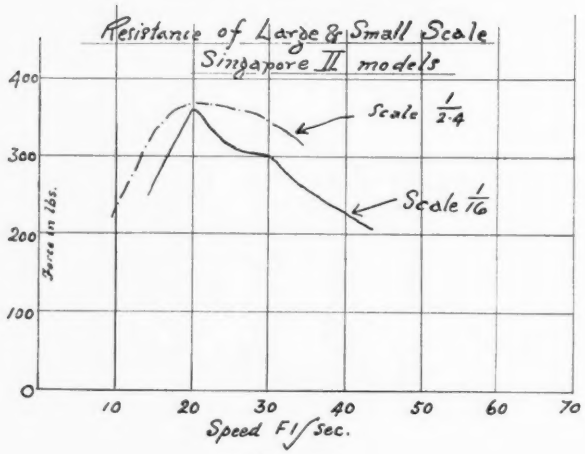

FIG. 11.

The one great disadvantage of tests on the large-scale model on a seaplane, as compared with the tests in a large tank such as that of the N.A.C.A., is that the tests are dependent upon the weather and water conditions. There are many days at a seaplane station like Felixstowe when the conditions are quite unsuitable. We are unfortunate in this respect in not having in this country a large inland lake, such as are plentiful, for example, in France and Germany. The German

tests were made on the Boden See, where the conditions are ideal for the greater part of the year.

The apparatus used at Felixstowe is suitable for measuring resistances in accelerated motion, and such measurements were made with the 111F apparatus. The resistances obtained in steady and accelerated motion are plotted against the speed in Fig. 12 and show that the virtual mass effect is only important at the higher speeds. At the hump speed there is a small positive effect causing an increase of resistance of about 2 per cent. At a speed of 60 ft. per sec. there is a negative effect causing a reduction of resistance of about 10 per cent., and this effect persists over the range from 60 ft. per sec. to 90 ft. per sec. The explanation of the negative effect may be that there is an effect on the water lift as well as the resistance, and that the former is the more important.

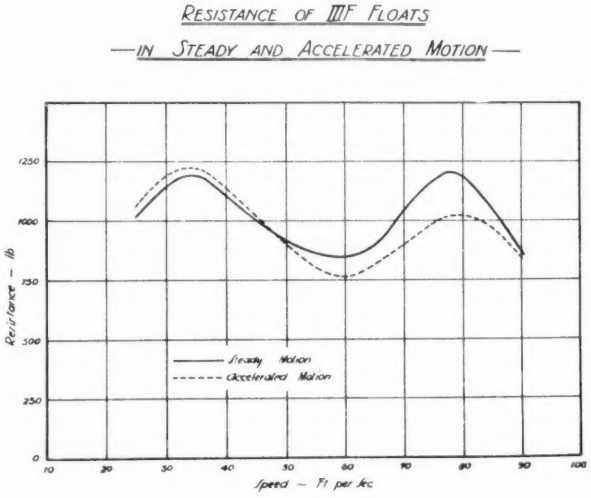

FIG. 12.

Indirect Scheme for Large Flying Boats

We now come to the final stage in our attempt to correlate model and full scale—the determination of the full-scale resistance of a large flying boat. The design of apparatus for the direct measurement is much too expensive, and we have to discard the direct method for what is known as the indirect method. This consists in the determination of the resistance from an estimate of the engine thrust and the air resistance, and from measurement of the acceleration during a take-off run. The resistance is determined from the equation

$$R = T - D - mf.$$

To assist in estimating the thrust during the take-off, measurements are made when possible of the static thrust. The drag is determined from wind-tunnel data. The acceleration is measured either by an accelerometer or by doubly differentiating the readings of a sensitive air log which is attached to a strut of the flying boat. The tests are always made in a very light wind, and in order to mean out the effect of water currents and wind, alternate runs are made in opposite directions.

It should, perhaps, be pointed out that an accelerometer fixed in the flying boat measures the accelerations in a direction which is only horizontal at one particular attitude, and that, in general, large corrections have to be applied to the readings to allow for the component of normal acceleration. A two axes accelerometer with a gyro recorder combined provides a very suitable instrument for enabling the correction to be applied.

The accuracy of the method was assessed during the 111F experiments already referred to. The forward acceleration was measured on a number of take-off runs, and the resistance was measured directly at the same time. During these experiments the resistance-measuring apparatus was useful in enabling the static thrust to be measured; the floats were fixed and the forward movement of the fuselage against the dynamometer was a measure of the thrust. The values of the resistance obtained by the two methods are plotted in Fig. 13. The agreement is, on the whole, good, the average discrepancy being of the order

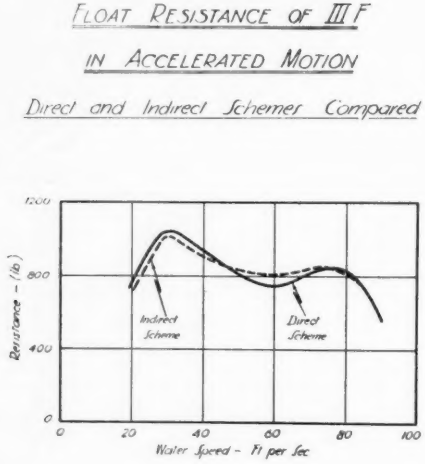

FIG. 13.

of 2 per cent. The maximum discrepancy is at 60 ft. per sec. and is about 7 per cent. It may be noted that the resistance obtained by the indirect method agrees better with the model resistance at low speeds and worse at high speeds than does the resistance obtained by the direct method.

The tests on the 111F show that the indirect method may be considered to give a satisfactory determination of the resistance. There is no reason why the same order of accuracy should not be obtained for a flying boat as was obtained on the 111F, except that the determination of the static thrust on the former is more difficult. I feel that a thrustmeter is essential on the flying boat if a suitable accuracy of determination of resistance is to be achieved. The design of a suitable thrustmeter for this purpose should not be difficult. An alternative would be to measure the thrust for a complete nacelle in the new full-scale wind tunnel now being erected at the R.A.E.

The development of the methods of determining water resistances on large-scale models and on the full-scale at Felixstowe has, on the whole, progressed satisfactorily. A good deal of the time available for research during the last

three years has been devoted to this problem, but we have not yet reached the stage of obtaining a comparison of the resistance of a small model, a large model, and the full-scale flying boat hull. Until that comparison has been made, preferably for several hulls, it will not be possible to say what the scale effect on the small models is.

There is, however, some evidence that the scale effect may be important. The evidence on the 111F has already been given (Fig. 7), suggesting that the model resistance is about 10 per cent. low. There is some further evidence from model and full-scale tests of two entirely different hulls on the "Singapore II." No. 1, the original hull, was found to porpoise when heavily loaded, and after a considerable amount of testing had been done in the tank, hull No. 2, which in the tank was found to be free from porpoising, was evolved. It was found

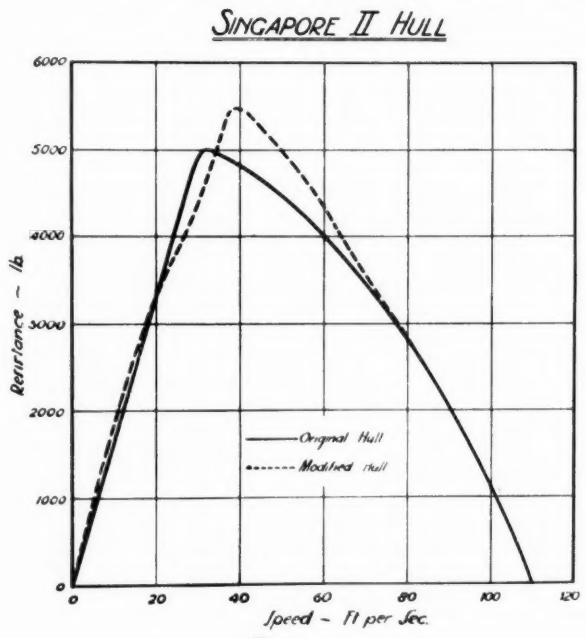

FIG. 14.

that the resistance of the hull model was greater than before, but it was considered that a sacrifice ought to be made to secure a stable hull. The resistances of the models, which were one-sixteenth of the full scale, compared at the full-scale attitude, are shown in Fig. 14. The resistance of No. 2 hull model is greater than that of No. 1 over most of the range, and the take-off time would be expected to be a little longer; a rough calculation shows that the maximum weight at which No. 2 hull could be taken off should be about 1,000 lbs. less than the weight for No. 1. On the contrary, it was found that the No. 2 hull could be taken off at a weight of 32,000 lbs., as against 30,000 lbs. for No. 1 hull, corresponding roughly to an average decrease of resistance of about 7 per cent. No other relevant difference than the change of hull was made to the "Singapore."

It is hoped in due course to investigate the discrepancy by making tests on large models of both hulls by means of the " Moth " apparatus. For the present it would appear that the results of tests on models as small as one-sixteenth scale must be accepted with some reservation.

Before leaving the question of resistance measurements, I should like to suggest that the more fundamental problem of separating the skin frictional and wave-making resistances is one which ought to be earnestly tackled in the near future. The problem is involved. One complication is that the successful solution involves the development of a scheme for measuring the wetted surface of the models under test. A photographic scheme appears to be the most promising. I feel sure that the observation of the wetted surfaces of different scale models would throw a good deal of light on the problem of scale effect on resistance.

Stability

In addition to low resistance, it is necessary that a seaplane should possess adequate stability and seaworthiness. These two qualities are by no means synonymous, although the former is generally necessary to ensure the latter.

It is necessary to consider both static and dynamic stability. The former is usually considered to include the stability when the seaplane has a small forward or backward movement relative to the water, such as occurs when the seaplane is moored to a buoy.

Static Stability

Adequate static longitudinal stability is not difficult to ensure if the other requirements of good design are met. A tendency to nose under at low forward speeds is, however, sometimes obtained with racing floats which are made in a nearly streamline form.

A seaplane with a single float is unstable laterally on the water and has to be stabilised by the use of wing-tip floats, inboard floats or stubs, or alternatively the seaplane may be replaced by two floats symmetrically disposed.

Of all the possible arrangements, wing-tip floats cause the least additional water and air resistance, but they are more likely than their alternatives to be damaged in heavy seas, particularly if the flying boat gets into a position side-to-wind. Stubs are generally considered to be the most seaworthy arrangement, although the loads imposed on them during a heavy landing are considerable. Stubs are, however, very heavy, cause additional resistance on the water, particularly near the hump speed, and have a high air drag. The general opinion of designers in this country has been that the obvious disadvantages of stubs more than outweigh the possible advantages. On the other hand, Dornier has built a very successful series of flying boats, culminating in the Do.X, all stabilised by stubs. The twin-float arrangement gives improved lateral stability, inferior longitudinal stability, and some decrease in aerodynamic efficiency. There is also a difficulty in large aircraft of this type in making the structure sufficiently rigid to take the float loads which are rapidly transferred from one float to another in heavy seas. The general consensus of opinion is that this type is not so seaworthy, weight for weight, as a flying boat with a single hull.

The effect of different lateral stabilisers on the resistance of a flying boat hull has been calculated by Coombes and Read (Ref. 5). It is found that the increase of resistance caused by stubs is such as to reduce the take-off weight of a flying boat by 4 per cent. as compared with the weight of the boat when fitted with wing-tip floats. Inboard floats reduce the take-off weight by about 3 per cent. There is a little uncertainty in the conclusions because the calculations are based on resistance measurements which happened to be available and are not strictly comparable for the different arrangements. It is very desirable that special tank tests should be made in order to obtain a more direct comparison. Wind

tunnel tests are also required in order to reduce as far as possible parasitic and induced drag. One important point is to reduce the induced drag of stubs, which in all successful designs up to the present have been set at a large angle to the wings.

Probably the best way to tackle the problem would be to get out two complete designs of flying boat, one with wing tip floats and the other with stubs, and if the estimated performances on the water and in the air, based on a comprehensive series of tank and wind tunnel tests, were comparable, to construct them. This is a piece of practical research which should appeal to the designer.

Before leaving the question of static stability, I should point out that in a twin-float seaplane the longitudinal and lateral stabilities are closely connected when the displacements are large. As the seaplane rolls over the submerged float tends to sink at the stern, and in the limiting condition the seaplane rolls over about an axis between the longitudinal and lateral axes. The catastrophe known as rolling over backwards is most likely to occur when the seaplane is drifting astern, and has occurred on several seaplanes with inadequate buoyancy.

Dynamic Stability

When moving forward at a speed greater than the hump speed, a seaplane with a single hull is laterally stable, and dynamic lateral stability presents no difficulties. The longitudinal stability, however, requires a good deal of consideration, for we are faced with the unpleasant and little understood phenomenon of " porpoising."

The word porpoising is generally understood to mean longitudinal instability on the water so violent that the seaplane periodically leaves the water. There is, however, some difference of opinion as to the degree of instability which should be called porpoising. It is proposed to use the term in this lecture for all degrees of instability in place of the less graphic term longitudinal instability, and to qualify it by the adjectives gentle, moderate, or violent.

In the early days of seaplane development porpoising was a frequent occurrence. The opinion held in those days was that it was most important to avoid porpoising at low speeds, where there was little elevator control, and that porpoising at higher speeds was a necessary evil. Now-a-days, when take-off speeds are much higher, porpoising at the higher speeds is a source of danger, particularly during take-offs and landings in rough seas.

The early porpoising generally took place at a relatively small attitude (nose down) and could be sometimes eliminated by moving the centre of gravity of the seaplane further aft. In the last few years several flying boats which porpoised, more or less violently, have been sent to Felixstowe for test. Observation of the behaviour of these boats and of the models in the tank shows that there are several different kinds of porpoising. For instance, one boat was found to be stable when running on the forebody and violently unstable when trimmed aft. For another boat, the reverse held. The remedies for these two boats would, of course, be quite different.

As a result of experience it may be said that if the experiments on the model seaplane in the tank are properly made, the behaviour of the full-scale seaplane can be approximately predicted. The general practice is that if, during the tests, a model is found to porpoise badly, it is modified until stability is attained. No standard procedure is adopted, and it may happen that scores of modifications are tried before a satisfactory model is achieved. The causes of porpoising are so complex that even our most experienced designers have, I think, only a vague conception of the causes of porpoising, or of what to do to eliminate it. It is evident that here is a field for research which may prove to be of the highest importance.

It is rather remarkable that, until recently, no one had attempted, either in this country or elsewhere, to analyse the stability of a seaplane moving on the

water. The analysis, although laborious, is not exceptionally difficult, and considerable progress has already been made, mainly by Glauert and Perring at the R.A.E. (Ref. 8), in laying a sound foundation on which future work can be built. The difficulty at the moment lies in the lack of knowledge of a number of the resistance derivatives, which can only be determined by special tank experiments. The determination of these derivatives is one of the most important problems which are to be investigated in the new R.A.E. tank.

Although at present the work on porpoising is incomplete, one important conclusion, which perhaps helps to throw some light on the phenomenon, has been reached as a result of the above analysis and some practical tests on models (Ref. 9). The motion of the seaplane has vertical as well as angular components, both of which are associated with forces and couples acting on the seaplane. Analysis shows that instability may arise either from lack of damping in pitch or from the interaction of various vertical and angular derivatives. In order to find out whether the former type of instability is possible, a simple test—in which the vertical position of the model was fixed—was made on four models, one of which was extremely unstable when given the full degrees of freedom. It was found that the models were quite stable, and thus the instability is always associated with the vertical motion.

Having eliminated the lack of damping in pitch as a possible cause, we can concentrate on finding the particular derivatives in the vertical motion which are likely to be associated with violent instability. Without giving the mathematical analysis of the motion, which is given in Refs. 8 and 9, and need not be repeated here, I may say that the two most likely culprits seem to be the changes of pitching moment with vertical position and velocity (Mz and Mw). In some hulls Mz is very large and in others small, and it appears that it is one of the derivatives which can be changed considerably by reasonable changes in hull form. Most of the derivatives cannot be changed appreciably in this way.

I should like to suggest that it is possible that porpoising may not be instability in the ordinary sense, but may be caused by the existence of two stable attitudes of the hull, separated only by a few degrees. A comparatively small disturbance in between these attitudes, such as may easily be caused by slightly choppy water, may be sufficient to throw the hull from one equilibrium position to the other. In support of this argument it may be said that it occasionally happens in tank tests that two positions of equilibrium are obtained, one in which the hull is riding on the forebody and the other in which the rear step is well immersed.

If this theory proves to be tenable the mathematical analysis will prove to be very complicated, because there will be a discontinuity in the values of a number of the derivatives at the attitude at which the rear step comes out of the water.

It may be thought that the direction in which research is proceeding is somewhat academical, and the practical man may say that he cannot see at present any information which will help him in design. It is hoped that most of the listeners to this lecture are convinced of the value of such research, but it may be pointed out that the hit-and-miss methods employed in the past, while providing a solution to the immediate problem, leave the designer just as much in the dark, so far as the future is concerned, as he was before. The determination of the resistance derivatives will show eventually which particular derivatives cause the instability, and it should be possible to find means of suitably altering these derivatives without great difficulty. In fact, the proposed line of research is very similar to that which can be said to have satisfactorily solved most of the stability problems of aerodynamics. Unfortunately, at present we are in a position analogous to that of about 1912 in the aerodynamic work, when the determination of the aerodynamic derivatives was commenced by Bairstow,

following what might then have been regarded as the purely academical analysis of Bryan.

I think it is desirable that the research work which is proceeding and which I have already described should be supplemented by less comprehensive tests in which a model is modified in various ways and its behaviour in the tank observed under different conditions.

It is important for these tests that complete models, dynamically similar to the full-scale aircraft, should be used. Fortunately the technique of constructing such models has been developed by the R.A.E. to a high degree of perfection in connection with spinning work, and no difficulty in making models sufficiently strong to stand up to the water forces is anticipated.

It is very important that the modifications made to a hull to improve the stability should not increase the hull resistance. It is quite possible that low resistance and good stability qualities may be, to some extent, conflicting requirements, and any research work on stability should therefore include frequent measurements of resistance.

Seaworthiness

The third good quality considered to be essential for a seaplane is seaworthiness under reasonable conditions. The seaworthiness of a flying boat depends very largely on its size, and the same seaworthiness qualities are not to be expected from a flying boat as from a ship of much larger dimensions. The most that can be expected from a flying boat weighing about 30,000 lbs. is ability to take-off and alight in a five- or six-foot sea.

One aspect of seaworthiness has already been discussed under the heading of lateral stability. There is a second aspect of considerable importance. It is an essential for good seaworthiness that in alighting the seaplane should not tend to leave the water after the first contact, even in disturbed water. This quality can easily be achieved by making the vee of the hull sufficiently deep, but only at the expense of an increase in resistance. A further slight disadvantage of a deep vee is the increased directional instability of the hull, requiring a large air control to keep the seaplane straight when the forward velocity is small. On the other hand, an important advantage of a deep vee is the reduction of loads on the hull during take-offs and landings, enabling a saving of structure weight to be made.

Further research work in the tank should produce hulls as seaworthy as the best of those at present in service, but with an appreciably lower resistance.

Measurements of Water Loads on Hulls and Floats

The structural design of hulls and floats is a problem of great complexity. As a result of years of experience, the designer to-day is able to design hulls which stand up reasonably well under the strenuous conditions of service. Recent tests at the R.A.E. have shown, however, that the structure weights of hulls can be appreciably reduced without loss of strength being incurred. It is not, however, within the scope of this lecture to deal with structure design, but only with the determination of the water loads which are actually applied to the structure.

The experiments which have been made with the object of determining the structure loads caused by water forces may be divided into three groups—(*a*) measurement of total loads, (*b*) measurement of hull pressures, and (*c*) measurement of loads in structural members. The third group of experiments gives directly the information required, provided that a sufficient number of measurements are made, but it is difficult to see how the method can be applied to such a complicated structure as a flying boat hull, although it can be directly applied to a float seaplane undercarriage.

I shall first give an account of the work which has been done and of that which is still in progress under the three headings, and shall then try to suggest

in what way the information obtained can be used to determine the stresses imposed on the structure.

Measurement of Total Loads

The first measurements of total loads appear to have been made on a model seaplane float at the N.P.L. in 1919 (Ref. 10). Models with different shapes of bottom were dropped into smooth water and the vertical motion determined. The expected result that the load is reduced as the angle of the vee of the hull becomes less was clearly demonstrated in these experiments.

The first full-scale measurements appear to have been made in the United States, in conjunction with measurements of local pressures on hull bottoms. Experiments were made on a twin-float seaplane (Ref. 11) and on a flying boat (Ref. 12). In the earlier tests, those on the twin-float seaplane, vertical accelerations only were measured. Two accelerometers were fitted, one at the C.G. of

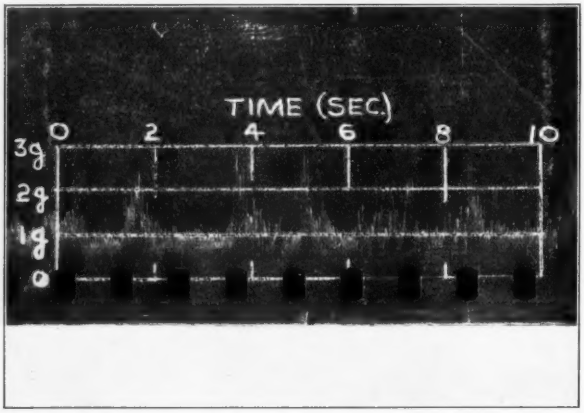

FIG. 15.

the aircraft and the other on the float skin. The two highest accelerations recorded on this seaplane at the C.G. were 4.3 g. and 3.8 g., both in pancake landings.

In the later experiments on the flying boat, longitudinal and lateral accelerations were measured at the C.G. in addition to the vertical acceleration, and the acceleration was also recorded by an accelerometer fitted in the hull bottom. The maximum vertical acceleration obtained at the C.G. was 4.7 g., but this is regarded as exceptionally high; an acceleration of 3.0 g. was rarely exceeded either in take-offs or landings. The maximum longitudinal accelerations reached was 0.9 g. during a landing, and accelerations of 0.7 g. were frequently attained during take-offs. The maximum lateral acceleration obtained during cross-wind landings was 0.5 g.

The conclusion was reached from the tests of both the twin-float seaplane and the flying boat that the accelerations in the float skin are of the order of 2 g. higher than those at the C.G. of the aircraft.

No information is given as to the duration of the high accelerations recorded on the float skin, and in fact the instrument used was somewhat unsuitable to determine this duration. The duration is, however, of the greatest importance. This is a question which will be considered in more detail later on.

Experiments similar to the American experiments are being made at the present time at the M.A.E.E. on different flying boats. Vertical and longitudinal

accelerations are being measured at a point in the hull about three feet above the keel. The maximum horizontal and vertical accelerations so far recorded are 3.3 g. and 0.6 g. obtained with an accelerometer whose natural period is one-twentieth second. Typical results are shown in Fig. 15.

Measurement of Hull Pressures

The first measurements of hull pressures were made in 1920 in this country by the N.P.L., in co-operation with the M.A.E.E., Isle of Grain, on an H.16 hull (Ref. 13). The instrument used to measure the pressure was a spring-loaded plunger which was forced back against the spring force when the water pressure exceeded some definite quantity. The movement of the plunger was recorded by the breaking of an electric current. Measurements were made at six places on the hull, all in front of the main step. The maximum pressure recorded in these early tests was 8.2 lbs./sq. in.

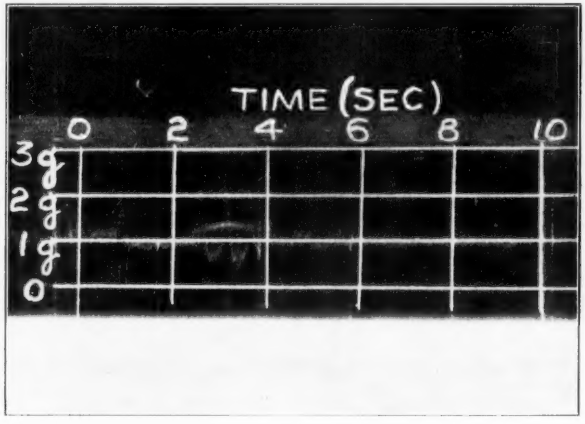

FIG. 15A.

Further experiments were made in 1924 on a P.5 hull (Ref. 14). Considerably lower pressures were obtained on this hull, although the angle of the vee was the same as on the H.16. The maximum pressure recorded was 4.6 lbs./sq. in.

Experiments on very similar lines were started in the U.S.A. in 1926. The instrument used to record the pressure was on a similar principle to the N.P.L. instrument, but was of a more elaborate design. Each pressure unit contained four pistons so that a range of pressures was obtained in place of a single pressure. The spring loading was replaced by air pressure, a method which had been tried without much success in the British experiments. As many as 15 units were used for most of the experiments. The preliminary experiments, on a single-float " Vought U.o-1 " seaplane, are described in Ref. 15, which also contains a detailed description of the apparatus. The experiments were continued on a twin-float seaplane (Ref. 11) and on a flying boat hull (Ref. 12). The largest pressure recorded, on the flying boat, was 15 lbs./sq. in. at a point just in front of the main step near the keel. Frequent pressures of the order of 10 lbs./sq. in. were obtained at many points on the forebody, both for the twin-float seaplane and the flying boat. Pressures of the same order were also obtained at the stern on the twin-float seaplane.

More recently an instrument has been designed for the measurment of hull pressures at the D.V.L. in Germany. The instrument, designed by Pabst, is described in detail in a paper by him in the D.V.L. Year Book for 1930 (Ref. 16), where an account of the different uses to which the instrument can be put is

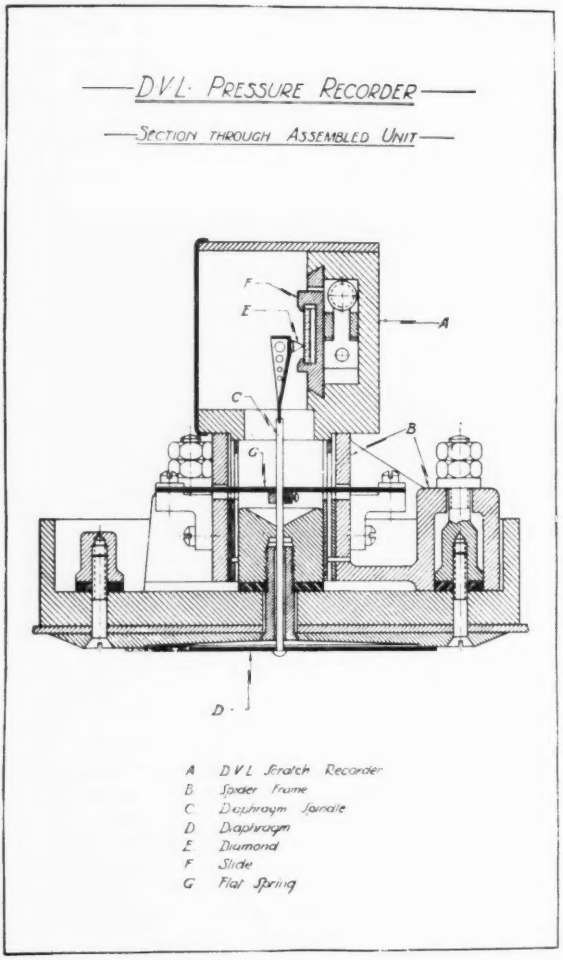

FIG. 16.

given. In particular it is used to measure the extensions and compressions of ties and struts, as well as for hull pressure measurements. When used for hull pressure work the instrument is attached to the centre of a diaphragm which is fitted into a hull bottom and is acted on by the water pressure. The arrangement of the instrument and diaphragm is shown in Fig. 16.

The instrument is a small, oblong box (A), which is rigidly attached to the ring on which the diaphragm is mounted by means of a spider frame (B). A push rod (C) is attached to the centre of the diaphragm (D). At the upper end of the push rod is a small girder on which is fixed a diamond point (E), which traces a record on a glass plate mounted in a metal slide (F) which is driven past the diamond. The motive power is supplied by an electric motor which is connected to the instrument by a flexible drive. The drive is connected to a two-speed gearbox which forms part of the instrument and which is further connected to a rotating shaft on which is cut a fine thread. A nut mounted on the screw thread is attached to the slide (F). As the shaft rotates, the slide is therefore driven along. The pressure of the diamond on the plate is adjustable by means of a spring (not shown in the diagram). Sideways movement of the push rod is prevented by passing it through a light flat spring (G) mounted on the spider frame. Two other diamonds, one connected to a solenoid, give a time record, and a datum line. A photograph of the instrument is shown in Fig. 17. On the right of the instrument is shown the glass plate, and on the

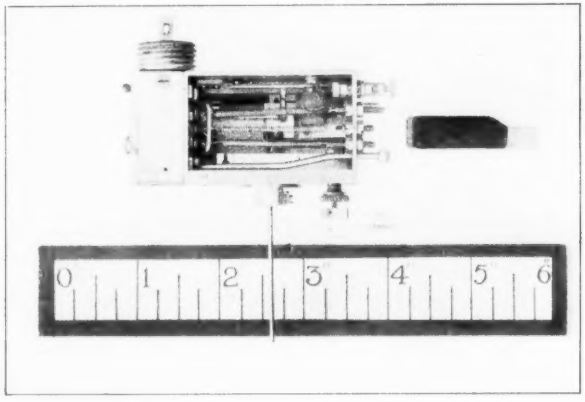

FIG. 17.

left the flexible drive connection is seen above the small gearbox. The small size of the instrument can be judged by comparing it with the inch scale placed alongside.

A number of pressure measurements were made with one of these instruments by the D.V.L. in 1930 and are described in Ref. 17. The instrument was fitted about 1 ft. in front of the step of a flat-bottomed wooden float fitted to a " Heinkel H.E.5 " seaplane. Pressures of the order of 20 lbs./sq. in. were frequently obtained during landings, and on one landing a pressure of 30 lbs./sq. in. was reached.

No tests on a hull fitted with a number of these instruments appear to have been done until the autumn of 1932, when a number of pressure measurements were made on the " Junkers W.33 " at Travemünde. One float was fitted with eight pressure recorders, and 20 extensometers were also fitted to the undercarriage struts. The results of these tests have not yet been published.

Pressure measurements in this country were started again, after a long interval of inactivity, in 1929. Preliminary experiments were first made to determine which was the most satisfactory instrument available for the purpose. Three instruments were tested, the first a British instrument, the second one of

the N.A.C.A. instruments, which was lent by the N.A.C.A., and the third a D.V.L. instrument of the type already described, which was purchased in 1930. The British instrument was found to be too bulky to be used in quantity, and the large inertia of its moving parts gave it a rather slow period (1/100th sec.). The N.A.C.A. instrument presented some practical difficulties. The air pressure has to be adjusted to correspond with the water pressure expected on the hull bottom. If the water pressure is less than the expected value none of the pistons may move, and an upper limit to the pressure only is obtained. On the other hand, if the water pressure is higher than the expected value, all the pistons may move and only a lower limit to the pressure is obtained. Even when the best record is obtained, it is difficult at times to form a correct idea from the stepped record of the true variation of pressure with time. The D.V.L. instrument was found to be very suitable. Its small size makes the fitting of a large number of instruments to a flying boat hull quite practicable. The period of the instrument, with the diaphragm in water, is of the order of 1/1000th second, so that quick period pressures of periods up to 1/200th second can be accurately recorded.

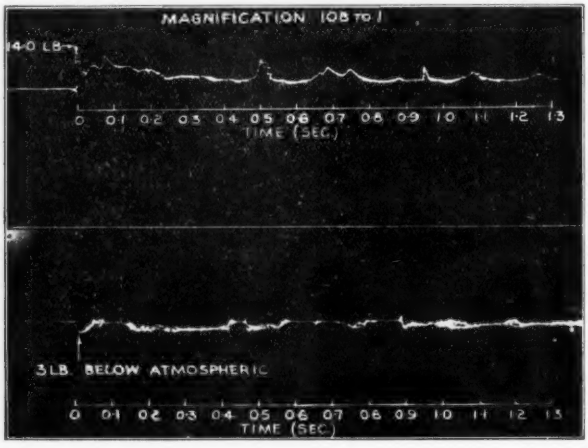

FIG. 18.

The only serious difficulty encountered was caused by hysteresis in the diaphragm. A redesigned diaphragm appears to have overcome this difficulty, but diaphragms are notoriously tricky pieces of apparatus, and further results are required before we can say that the new diaphragm is entirely satisfactory.

It would have been possible to redesign the British instrument on a much smaller scale, and no doubt with ultimate complete success, but it was considered that the delay which would be incurred was not justified, in view of the importance which was attached to the determination of pressures simultaneously at a number of places on the hull of a flying boat. It was therefore decided, since the D.V.L. instrument was undoubtedly far superior, to order a number of these instruments and to fit them in turn to hulls of different shapes. More than 20 of these instruments have been fitted to a flying boat, and pressure measurements have now commenced.

It was considered desirable that, before the systematic tests on a flying boat hull were commenced, experiments should be made to determine if the elasticity of the hull plating had any effect on the pressures recorded. A flying boat was fitted with two D.V.L. recorders in symmetrical positions just in front of the

main step. One instrument was mounted on the ordinary plating and the other on plating three times as thick which was further stiffened by brackets. After a considerable number of tests it was decided that the effect of the elasticity was negligible. An interesting and unexpected result was obtained however from the tests. Large differences in pressure on the two sides were recorded on a number of occasions before it was realised that these differences were caused by small amounts of drift or bank relative to the water. On one landing, which both pilot and observer reported as normal, large positive pressure was obtained on one side and a negative pressure on the other. Typical records of a landing with drift are shown in Fig. 18. A positive pressure of 14 lbs./sq. in. and a negative pressure of 3 lbs./sq. in. were obtained on this landing, which was made with a drift of about 9 ft./sec.

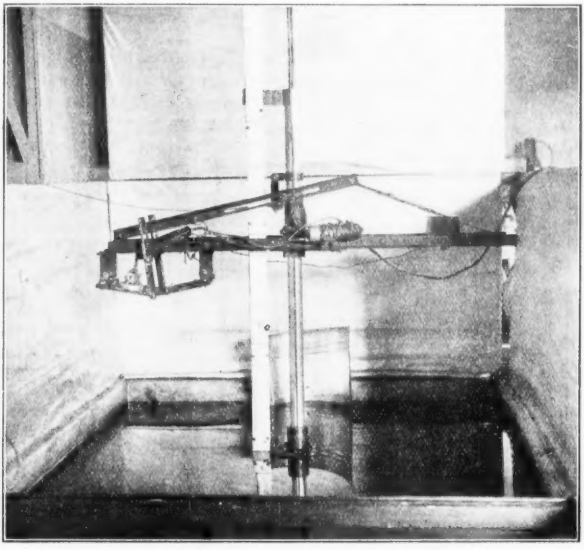

FIG. 19.

The large differences in pressure caused by drift do not appear to have been previously recorded. In the American experiments already described all the pressure units were fitted to one side of the hull and no attempt seems to have been made to measure pressures on both sides.

Further tests to determine the effect of elasticity were made in the laboratory. The apparatus illustrated in Fig. 19 was used for these tests. A small vee bottom, to one side of which a pressure recorder is fitted, is mounted on an arm which is arranged to slide vertically down a shaft into water. The angle of the vee can be quickly adjusted, and different thicknesses of plate can be easily fitted. Velocities up to 10 ft./sec. can be obtained with this apparatus.

Tests were made with different materials for the plating, and with the plating packed out with rubber jointing. No systematic differences in the pressure records were found which could be attributed to differences in elasticity. Four typical pressure curves for two different angles of vee are shown in Fig. 20. Pressures of 12 lbs./sq. in. are obtained for an angle of vee of about 160°, corresponding to an angle of the plate with the water of 10°. For an angle of

vee of 140°, corresponding to an angle of the plate of 20°, the maximum pressure is 5½ lbs./sq. in. The maximum pressures are reached in about 1/1000th second and about 3/1000th second respectively. The former time is of the order of the period of the instrument, and the difference in the two illustrated records in the

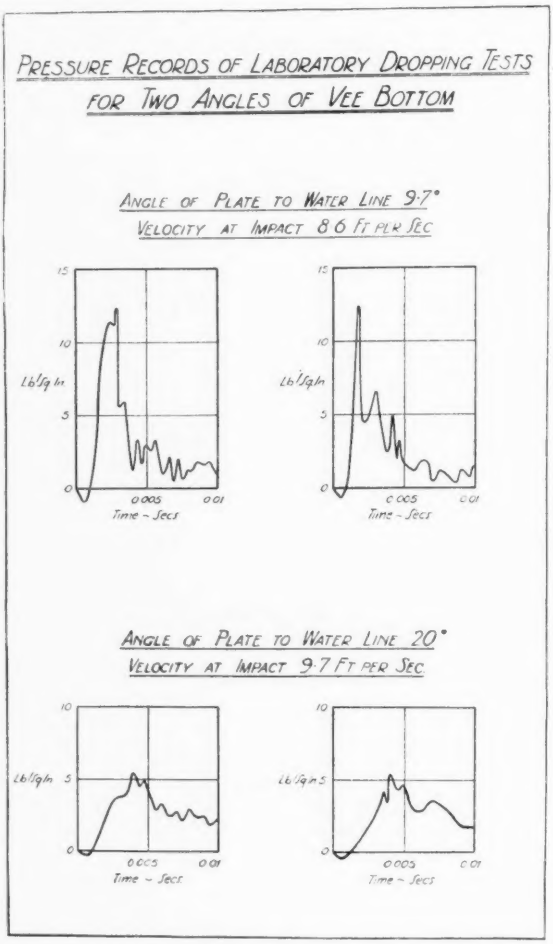
PRESSURE RECORDS OF LABORATORY DROPPING TESTS
FOR TWO ANGLES OF VEE BOTTOM
ANGLE OF PLATE TO WATER LINE 9·7°
VELOCITY AT IMPACT 8·6 FT PER SEC
Lb/Sq In
Time - Secs
ANGLE OF PLATE TO WATER LINE 20°
VELOCITY AT IMPACT 9·7 FT PER SEC
Lb/Sq In
Time - Secs

FIG. 29.

neighbourhood of the peak pressure is caused by this. The steeper vee corresponds more closely to the hull shapes adopted by British designers (it is actually rather flat) and the period of the instrument is then sufficiently short for no appreciable error to occur in the record.

Measurement of Load and Structural Members

Little attempt seems to have been made to measure the loads in structural members of seaplanes except at the D.V.L. in Germany, where great interest has been shown in this problem. The first experiments were made on a " Heinkel H.E.9a " monoplane fitted with flat-bottomed floats (Ref. 15). A number of extensometers, whose recording units were similar to that in the D.V.L. pressure recorder, already described, were fitted to the struts of the undercarriage. In these experiments only vertical and horizontal forces were measured on the members attached to one float. No attempt was made to measure lateral forces.

From the measurements, the total vertical and horizontal loads were calculated for the float. The conclusion is reached that the maximum vertical load is about six times the weight of the aircraft The resultant force is found to be inclined backwards from the perpendicular to the float surface; the suggestion is put forward by Pabst that the backward inclination may be caused by the yielding of the float bottom under the shocks. There is a definite period, of the order 1/20th second, in the records of the extensometers shown in the paper.

As has already been mentioned in the Section dealing with hull pressure measurements, further tests were made at Travemünde on a Junkers W.33 during the Autumn of 1932. Twenty extensometers were fitted to the undercarriage struts, from which it was hoped to deduce the lateral as well as the vertical and longitudinal forces on the floats. The results of these tests are not yet available. No work of this kind has yet been done in this country, and I have seen no record of similar work in any other country than Germany.

The Direction of Future Research

We have seen that research into the loads on hulls and floats is being directed along three main lines, each involving very laborious and difficult experiments. It is, therefore, worth while considering carefully what information we are likely to get from each line of research, in order to avoid any unnecessary work.

The problem is two-fold. In the first place, hydrodynamical loads depending upon (1) the shape of the hull, (2) the shape of the water surface and (3) the velocity relative to the water, are imposed on the hull. In the second place, these loads cause relative movements and stresses in the structure.

I wish I could feel certain that the two parts of the problem are quite unconnected, but I feel that it is possible that the elasticity of the hull may, to some extent, affect the applied load. In so far as the elasticity of the plating is concerned, we have not been able to find any such effect, and it may be that the effect generally is small. It is of interest to note that Pabst (Ref. 16) suggests that the yielding of the bulkheads may cause a horizontal component of pressure.

The problem, however, is quite complicated enough without this interconnection. Considering first the hydrodynamical part, we find that a hull is subjected to loads which rise to a high value in a very short time and then rapidly die away. I imagine that a moving picture of the pressure system of a flying boat landing in a choppy sea would show successive peaks of pressure separated by 20 or 30 feet moving along the hull at the rate of about 100 feet per second. It is a formidable piece of work to determine this moving picture, quite apart from the problem of finding the effect of the pressure wave on the hull structure.

Is the effect of large loads applied for a short time of any importance? If not, the whole problem is simple and we need only consider relatively small steady loads. There is no direct conclusive evidence on this point, but it is common experience that a flying boat taking off or landing in a rough sea is

subjected to shocks which last for quite a short time, and it is generally under these conditions that hull failures occur. I think that we should find, if we were fortunate enough to get a set of pressure measurements on a hull at the instant of failure, that the failure could not be accounted for by the action of steady pressures. It may be necessary, therefore, to find the effect on the structure of loads whose time of application is small. This effect even on a simple member has not, so far as I am aware, received much attention. One would expect to find a relation between the applied load and the time of action necessary to cause failure; the relationship would, of course, depend upon the elastic qualities of the member. It would be a most valuable piece of research to establish the kind of relationship which exists.

I must confess that even with a complete knowledge of the load applied to a hull, and of the behaviour of a simple member under a rapidly changing load, I find it difficult to see how the last stage of the problem, the determination of the maximum stress in the hull members, is to be attacked. Extensometers of the D.V.L. type could be used, but the number required to give complete information would be prohibitive. Possibly the best procedure would be to replace groups of members, *e.g.*, in a bulkhead, with simple groups in which the stresses could be fairly easily measured.

The scheme of tests outlined above—I am afraid not very definitely—is very laborious and would take many years of research to complete, and yet I can see no alternative. Each step of the work is necessary. Measurements of stresses in members without knowledge of the applied loads will give some sort of an idea as to what is happening, but the stresses depend upon two independent quantities, the shape of the hull and its structure, which cannot be separated. For example, the stresses measured in the members of a float plane undercarriage may be low, either because the float has a good shock absorbing shape or because the float structure is very flexible. At the same time I do not want to suggest that the line of pure research which I have indicated as necessary for the complete solution should be the only one to be pursued. A problem which can be attacked by relatively simple methods is that of investigating the failures of hulls and floats which frequently occur just in front of the point of attachment to the rest of the aircraft structure. The failure is caused by the up load on the forebody. It is a comparatively simple matter to determine experimentally for a typical hull the bending moment which has caused the failure. Other *ad hoc* problems could also be solved similarly. But some caution would be necessary in applying the results to hulls of different shape and structure.

I am rather doubtful as to the value of the measurements of acceleration in this work. The fact that large differences in acceleration are experienced at the hull bottom and the C.G. of the aircraft (Refs. 9 and 10) shows that the accelerations act for a very short time. A quick period accelerometer is necessary to record the accelerations, and it would also record the accelerations in the structure caused by engine vibrations. The interpretations of the record would be very difficult. Further, it would be difficult, from a knowledge of the accelerations of individual parts of the aircraft, to determine the loads on the aircraft.

Conclusion

I have attempted to give an account of the work which has been done in recent years, and of the direction in which research is proceeding, on three of the most important problems associated with seaplanes—the reduction of resistance, the elimination of instability, and the formulation of structure loads. When I was first asked to give this lecture I thought I should be able to record considerable progress on these problms in recent years. Now, in reading through the lecture, I am impressed with the small amount of work which has been done in relation to the vast fields of research which remain to be explored. If the

lecture helps to stimulate interest in a hitherto somewhat neglected subject it will have served a useful purpose.

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Discussion

The Chairman: Mr. Garner had compressed into a comparatively short space of time an immense amount of material, and had dealt with it in a very admirable and concise way. One of the questions he would like to ask Mr. Garner had relation to the latter's remarks about the momentary loads. The loads that came on to the hull of a flying boat in landing were certainly very sharp and very short, and it was important to determine the effect that they would have on the upper part of the structure. In his paper the lecturer spoke of a difference of 2 g. in the accelerations. The rate at which the impulsive forces moved from the immediate point of impact with the water to the upper part of the hull depended upon several factors. At any rate, they could not possibly move more quickly than the velocity of sound in the structural members. He would like the lecturer to give them some idea of the distance that such a sound would move in the very short periods of time of which he had spoken. The duration of these very high pressures was usually measured in thousandths of a second. He thought the question had a very important bearing upon the distribution of loads on impact. Distribution might proceed more slowly if there was actual bending, or inelasticity of parts, or play between parts.

Another point raised by the lecturer was that of the interpretation of model results in a tank. In that respect their practice was derived from the naval architect. In the latter's work most of the drag was attributed to wave making and a smaller amount to skin friction. The Chairman understood that it was the practice of naval architects to use Froude's law after making an estimated correction for the skin friction factor. In seaplane work, so far as he knew, they had not taken account of the skin friction factor, because the wave-making effect was so vastly greater in a seaplane than it was in a ship. On the other hand,

when a seaplane was near the taking-off point the draught was very much reduced, and it might be that at such speeds the skin friction would predominate over the wave making. That might seriously affect one's prediction of the full-scale results. Research work upon those lines certainly seemed to be called for, and he would like the lecturer to tell them a little on that subject.

Mr. Garner's remarks were not very favourable to the stub type of float, but he had made what the speaker thought was a good suggestion, that if alternative designs were made for the same craft with the ordinary types of float and the stub type, and models were tested in a tank, very useful information could be obtained as to the wave, drag, and porpoising effects. It was such a good suggestion, said the Chairman, that he would see that it was brought to the attention of the Director of Scientific Research! He congratulated the author on having broken new ground in the ingenious and amusing film he had shown.

In concluding, the Chairman welcomed Group-Captain Miley, the Commanding Officer of the Felixstowe Station, where so much excellent research work had already been done, and where they looked for so much from the future.

Group-Captain MILEY: Seaplane research being the youngest branch of the tree of aeronautical science, it was yet too early to expect much definite information upon which the designer could base his designs. He entirely agreed with the lecturer's statement that the subject was still in its infancy. The paper would certainly do much to stimulate interest in the subject, and he was sure that the great amount of time and labour that Mr. Garner and his Staff had given to the preparation of the paper would benefit the development of seaplanes. He thought that Mr. Garner was wise to assign no order of relative importance to the three main aerodynamical problems with which he dealt in the first part of the paper, but one had a suspicion that in his own mind their relative importance was that in which they were written down. This suspicion was supported to some extent by the fact that there had been a tendency in some recent designs to sacrifice dynamic stability in the interests of low resistance. Group-Captain Miley entirely agreed with Mr. Garner's statement that the reduction of water resistance was essential to progress, but he believed that a very good degree of stability could be obtained in conjunction with a sufficiently low resistance if sufficient attention were given to both requirements. Indeed, modifications which had been made to one design which originally failed in dynamic stability had shown this to be possible. In any case, the badly unstable seaplane was practically useless under service conditions, however good its performance might be.

The speaker then dealt with the subject of lateral stability. He had had a little experience with the Dornier type on the Pacific Coast of South America, and was very impressed with the advantages which that system possessed when taking off in a swell. The concentration of the whole of the float system near to the centre line of the machine allowed much greater freedom in taking off out of wind, a course which might be necessary if there were any large swell running, as was frequently the case in the Pacific. It was in fact the custom there to take off normally across the wind, as the pilots kept dryer that way, but this would hardly be permissible with our conventional types, owing to the risk of damage to the wing tips and floats. Although he fully realised the disadvantages, from an aerodynamic standpoint, which this type possessed, he felt that the advantages were sufficiently great to include its further development as a research item. Turning to the subject of dynamic stability, he found it a little difficult to accept Mr. Garner's conclusion on the effect of the vertical motion of the seaplane on its longitudinal stability. According to Mr. Garner, the instability was always associated with the vertical motion, but this conclusion was based on a limited number of experiments. Certainly the angular motions experienced were the ones which alarmed the pilot, and were the most dangerous, and it was a little difficult for him to believe that these were due to the small vertical displacements which the pilot scarcely felt. In any case, the experiments

referred to could not be repeated in the full scale, as there was no means of holding the c.g. down to a perfectly horizontal path. This brought him to his last point. When he was previously associated with the development of seaplanes some years ago, the resources for research were very much more limited than they were at the present day, and the large majority of experiments with models were *ad hoc* experiments to obtain a stable form with a reasonably low resistance for each particular design. In those days it was found that if the model were stable the full-scale seaplane was also stable, and it frequently happened that a slightly unstable model produced a perfectly stable full-scale machine. Recently it appeared there had been cases of stable models which, when built to full scale, had been unstable. He very much doubted whether this could be attributed entirely to the search after reduced resistance, to which reference had already been made, and he would like to ask the lecturer whether this result could be due to changes in the technique of tank trials. He thought it was not unfair to say that tests of similar models in different tanks produced different results, and if that last statement were at all true—he made it merely as a suggestion, not as a statement of fact—it would seem that tank technique might have something to do with it.

Mr. Gouge (Messrs. Short Brothers) : In general he agreed with the lecturer's remarks, but he would like to ask him one or two questions, although it was difficult to put technical questions on the spot and he would prefer to submit them in writing. In Fig. 1 Mr. Garner showed resistances of a model hull in a large tank as compared with those measured in a small tank. He would like to know whether it was the same model as that referred to in Fig. 14. He believed they were the same models; if so, it would appear that resistances measured on a small tank would give results nearer the full size than those measured on the large tank. He was of the opinion that practically the whole of the difference could be accounted for in two ways. One was due to the moment round the c.g. due to engine thrust. In the first model it was rather difficult to alter the angle of the hull. In the second case it was very much easier. This might have the effect of angling it forward slightly. He thought that by far the most important effect was the effect of acceleration. During a period of rapid acceleration it might not be possible for the waves to reach the same size in the time, and therefore the back end of the hull might not be touched in the full size as it was in the model. Mr. Gouge thought that this was probably the most promising line of research, apart from skin friction resistance as compared with wave-making resistance. Regarding the measure pressures on hulls, could Mr. Garner give them any idea over what area pressures of 14 lbs. per square inch were obtained, and how did the area of the German instrument compare with that of the instrument used by Mr. Baker in the original test on hulls? While it was possible to get these high pressures locally and they might travel as had been indicated, Mr. Gouge thought that over the whole there was no great pressure.

Major Penny (Air Ministry): It was very encouraging that they had at last had a research lecture on marine aircraft delivered to the Society. For the last three years Mr. Garner had been active in initiating many important lines of research, some of which Major Penny hoped would materialise in the near future. When Mr. Garner went to Felixstowe, in 1929, in many respects the knowledge of hydrodynamics as it affected marine aircraft was comparable to the position of aerodynamics in 1914. If this showed that there was a lack of vision regarding the great possibilities of the use of the sea as an aerodrome, the reproach was not to this country alone, but to the world. The remarks on the different methods of attaining lateral stability of flying boats on the water were very interesting. There would never be any definite conclusion on the relative merits of stubs and wing-tip floats until flying boats were built to the same specification, one with wing-tip floats and the other with stubs. The lecturer had referred to the research which was proceeding at the R.A.E. tank on porpoising. He (Major

Penny) knew of cases in which, after three months of tank testing daily of model hulls to try and eliminate porpoising, over 120 modifications were tried out. Had a satisfactory technique existed this work would not have been done on the hit and miss principle, and much time and money would have been saved. It was a pity that the lecturer had not dealt more fully with seaworthiness. Paradoxical as it might seem, the main characteristic of seaworthiness was ability to get away from the sea as rapidly as possible. This entailed a low horse-power surface loading, and as this feature was antagonistic to other qualities a compromise had to be made. Then he would like to inquire how the lecturer proposed to get the comparative value of loads on hulls constructed to different lines. Could it not be obtained by testing a scale model on the Moth superstructure? It was well known that hulls turned out by different firms bore a family likeness. A representative model hull from each family would give the necessary comparison. Another important question brought out by the lecturer was the uncertainty of the effect of large loads for short periods. Major Penny suggested that as a preliminary measure a section of a hull should be rigged up and tests applied.

Captain NICOLSON (Messrs. Saunders-Roe): Mr. Garner had been extraordinarily successful in his lecture dealing with flying boats. So many interesting points had been brought forward in the paper that quite a long time could be profitably spent in discussing them.

Captain Nicolson stated that up to a certain point a high speed hydroplane is the same problem as a flying boat, while it is on the water. He had a considerable experience of porpoising of both types of craft and was therefore interested in Mr. Garner's remarks on the jumping of flying boats.

Captain Nicolson recalled an experience that he had had many years ago with one of the old hydroplanes, namely, when she was porpoising she did about 80 miles an hour, but when she was stable she dropped about 12 miles an hour.

On another occasion he witnessed two boats racing which were designed on similar lines, but one porpoised much more than the other. Subsequently her bottom was modified to conform to the same lines as the steady boat, and in the next trials she dropped as much as 8 seconds per mile. Therefore it seems that the momentary reduction in resistance as the boat leaves the water is not counteracted by the increased resistance at the moment of impact when she again lands on the water.

The Chairman had said that naval architects took into account skin friction as well as wave resistance. That was true, and was very important, and particularly if the boat were full lined.

Captain Nicolson was surprised to hear that no account was taken of skin resistance of some flying boat hulls in tank tests, as the correction for skin friction is one of the important parts of the naval architect's calculations; this should also be noted in flying boats as the wetted surface is considerable until the hull has passed the hump speed.

In tank tests the naval architect usually tabulates the total resistance by adding the wave resistance to skin resistance and the resistance due to excessive model friction, or it may be taken in terms of horse-power, when the h.p. due to wave resistance would be added to the h.p. due to skin resistance plus h.p. due to excessive model friction.

In most cases if no account were taken of the skin resistance there would be a loss of 10 to 20 per cent. of the horse-power required.

Mr. Garner had said that flying boats had a lot to do before they could carry out long-range flying, owing to the hull becoming unstuck from the water. The speaker suggested as a line of research taking up the boat lightly loaded and refuelling it in the air. Mr. Lord and the speaker have patented a simple and practical method of refuelling in the air, specially adapted for flying boats

in any weather, which would increase the range of flying boats by at least 50 per cent.

Captain Nicolson congratulated Mr. Garner on bringing forward the claims of the flying boat, which had been neglected for many years, not only in this country, but throughout the world.

Mr. McKinnon Wood (Royal Aircraft Establishment): This work was very difficult, and the accuracy attained was remarkable, particularly by the indirect method. It was a matter of great surprise to the speaker, who at one time had thought that that method was quite hopeless.

Mr. Garner had treated the tank rather as if it were a wind tunnel, and had not distinguished between the effect of the side walls and the effect of the bottom, which reacted on the model in an entirely different way. Mr. McKinnon Wood was inclined to believe that one could quite safely test a model of length equal to the width of the tank so far as the effect of the side walls was concerned. The effect of the bottom presented an entirely different phenomenon, which was associated with the velocity with which a wave naturally travelled down the tank. He thought that the differences found by the lecturer between one tank and another were much more likely to be due to the depth than to the width. Taking a 12th-scale model, five feet of water represented 10 fathoms. It was quite possible that a test done in a smaller tank was more analogous to the conditions in the fairly shallow water in which a seaplane took off than a test in a bigger tank.

He was inclined to agree with Group-Captain Miley that Mr. Garner had jumped rather rapidly to the conclusion that porpoising was necessarily a phenomenon involving both a rising-and-falling and a pitching motion. He had quoted certain experiments which did not seem to be conclusive evidence. He was not convinced that it was impossible to get porpoising as a motion involving only freedom-pitching. Mr. Garner had described a method of measurement of derivatives which they were developing at Farnborough. A balance was being designed which would oscillate the model, vertically and in pitch, and record the forces continuously; and in that way they could obtain the derivatives. The subject might prove to be more complicated than might appear at first sight, because the derivatives might vary very rapidly with the frequency of the oscillation of the model, and a trial and error process would then be required to work out the stability. Until they had measured the derivatives it was impossible to say how this would turn out, but the matter was well worth pursuing.

(*Communicated*).—There is one other point on which he would comment. Mr. Garner suggests that conformity with Froude's Law of Corresponding Speeds may be unnecessary when the model is planing on the water, particularly when near the speed corresponding to the take-off. He also says that the size of model is limited by the speeds of the tank by virtue of this law. If the supposition that Froude's law can be ignored at the higher speeds proves true, the limitation of size by available speed is not removed, but the limit is raised. If, for example, they find they could depart from this law from two-thirds of the take-off speed up, they would be able to double the size of the model to which available speed restricts us. He thought this a not unlikely conclusion.

Sir A. V. Roe: He emphasised the point raised by Captain Nicolson with regard to refuelling in the air. No doubt it was very difficult to get a flying boat off the water with a big load.

Mr. Lower (Messrs. Short Brothers): There was a point that no one had hitherto mentioned, and that was with regard to the Lecturer's remarks on Hull No. 1 and Hull No. 2. Mr. Garner stated that the full-scale results were not comparable with the model results. The resistance on the No. 2 model was higher than that of No. 1, whereas the actual machine when modified to correspond to the former actually took off with a greater load than when it represented the form as on model No. 1.

Mr. Garner had not indicated so, but actually No. 2 hull model ran over the " hump " period, at an angle greater by about 4° than did No. 1, therefore the wing lift obtained in full size would be greater in the case of the modified boat. The model tests were conducted assuming the same lift in both cases, and were therefore not truly correct. This would seem an important point, since the load with which a flying boat can take off is governed by the value of the resistance over the " hump " period.

Captain G. T. R. Hill (Westland Aircraft Co.) : The eternal problem of stub versus wing floats came up again and again. The suggestion that direct comparative designs should be prepared was, of course, a good one, but he did not think that the problem would be settled unless other considerations were brought in. The standard trouble was that there were so many variables. The advantage of the stub wing float over the wing tip float—some people liked to put it the other way round—depended to a considerable extent upon whether one was imagining a biplane or a monoplane type. It seemed to the speaker that wing tip floats were more easily fitted to the biplane, while the stub wing mated up perhaps more harmoniously with the monoplane structure, as demonstrated in a recent paper before the Society by Dr. Dornier.

Turning to another subject, the lecturer discussed the question of the rate of loading on a stressed member and its effect on strength, and reminded them that the effect on even a simple member had not, so far as he was aware, received much attention. Capt. Hill remarked that the point was one of great interest, and he was able to provide a small piece of definite information as the result of some experiments which were carried out at the Westland Aircraft Works some years ago. They were working on the design of an undercarriage with high shock-absorbing qualities, and their experiments consisted in dropping a weight equal to that of a light aeroplane through several feet. The shock-absorbing material was mild steel, and it was found to be capable of withstanding stresses about 20 per cent. greater, when the time of loading was one-tenth second, than when it was some minutes, as was usual in the case of ordinary tests in testing machines. The point was one of importance, and until they could get further information on the matter he was afraid that they would find grave discrepancies between estimated and actual strength. The increase of stress under rapid loading, he felt sure, was characteristic of the material of which their bodies were made. Otherwise it would be impossible for anyone to withstand the effect of high diving into water. He found the film showing the pressure wave very informative, and he hoped that there would be a meeting of the Society in the not too distant future at which they would see the estimated pressure wave translated into a true measurement and shown as a real cinema film.

Mr. D. R. Pye (Deputy Director of Scientific Research, Air Ministry) : He understood that the main disadvantage of the stub wing was that, in order to be effective on the water, it had to be set at such an angle with the hull as to be stalled when in flight. He asked whether it might not be possible to design a mechanism whereby the angle of the stub wing with the hull could be altered in the air after taking off, and then readjusted to the proper angle for landing. There was another point which might be worth while considering. Early in the lecture Mr. Garner stated that he regarded the thrustmeter as an essential piece of apparatus for further full-scale measurement of water resistance. The thrustmeter would give the mechanical pull in the airscrew shaft. From that would have to be subtracted the reaction of the slipstream on the engine nacelle and the struts supporting it before one could get the net effective pull of the airscrews from which to derive the water resistance. Could the lecturer say what was likely to be the magnitude of corrections and with what accuracy they could be gauged? Was the direct measurement of water resistance by means of thrustmeters likely to be more accurate than the indirect measurements of which examples had been given in the lecture?

Mr. KORVIM KROUKOVSKY, Chief Engineer, Edo Aircraft Corporation, U.S.A. (*communicated*): It has been the experience of his company that lack of strength or rigidity of twin float gear is usually caused by failure to provide complete bracing in the float gear, and by depending for support on the rigidity of the fuselage structure. Neither American nor English airworthiness requirements contain any provision for the torsional strength of the bracing. When the seaplane is taxying diagonally across waves, so that bow of one float and stern of the other are on crests of two following waves, the torsional stresses are set up in the float attachment gear. The sizes of all members designed on basis of landing conditions are usually sufficient to resist these stresses, provided that the designer did not fail to provide complete bracing. If some of the bracing, such for instance as wires between spreader tubes in plane of float decks, were left out as not needed in the conditions covered by the usual stress analysis, the gear will not be able to resist torsion, and severe torsional stresses will occur in the fuselage structure.

No trouble is experienced in making satisfactory twin float installation if the precaution is taken to have diagonal bracing in all parts of the float attachment gear, even though some of this may be redundant and apparently not absolutely necessary.

Effect of Sharp V.

The beneficial effect of sharp V bottom on reducing the bending shocks and improving seaworthiness is universally recognised, but is always stated with reservation that this is done at the expense of resistance at take-off. It appeared to them that this reservation is accepted much too placidly, and that too little research is being made to determine whether a float with a sharp vee can be proportioned to be equal or even superior to the flatter types. The hump resistance may be described as the resistance of the float at maximum speed as displacement boat, or alternatively as resistance at minimum planing speed. The float with sharp V evidently represents a better displacement boat, and will permit certain increase of hump speed and decrease of resistance. The planing resistance of the float at hump speed is primarily the wave-making resistance, similar in nature to the induced drag of aerofoils. It decreases rapidly as the speed is increased. It appears, therefore, that hump resistance is likely to be reduced by sharp V, provided the speed at which it occurs is properly adjusted.

At high speed at least one-half of the total resistance is frictional, and sharp V bottom presenting more surface causes increase of resistance. This, however, can be reduced by provision of longitudinal steps or scallops of proper proportions, so that at high speed the chines are clear and the effective beam of the float is reduced to about 60 per cent. of the full beam. The effectiveness of such scallops increases with sharpness of V, with resultant decrease of total resistance.

Their company had investigated these theories in both towing basin models and full-size seaplanes, with the result that all new models of floats are designed with 25 to 30 degrees of deadrise, while 20 degrees was standard heretofore. In the summer of 1931, the Department of National Defence in Canada made comparative tests of older 20-degree floats and newer 30-degree floats, supplied by our Canadian licensee. The tests were made on the same seaplane, at the same loads, and were strictly comparable. They showed that in calm, glassy water the take-off on 30-degree floats took about 25 per cent. less time than on 20-degree floats.

REPLY TO DISCUSSION

The Chairman had asked if there was any connection between the rate of transmission of load in a hull structure subjected to rapidly applied loads and the velocity of sound waves in the structure. It was usual in structural problems to assume the velocity to be infinite and he thought it was safe to do so in this problem. The sound wave would travel 17 feet in 1/10ooth of a second.

The Chairman and Captain Nicolson both referred to the difference in procedure adopted in determining the resistances of ships and seaplanes. The lecturer said that on ship work corrections for skin friction were always applied. He was not very familiar with the details of the method adopted, but apparently the skin friction is assumed to be of the form kSV^n, where S is the wetted area, V the speed and k and n are constants whose values depend upon the nature of the surface of the ship and the length of the immersed surface. In practice n is nearly equal to 2. It appeared to the lecturer that the value of k must depend upon the speed and that the skin friction should really be expressed in the form $\rho SV^2 f\,(Ve/\nu)$, the form usually adopted in aeronautical work.

The variation of k with the size of the ship is determined experimentally for different surfaces, and since the wetted area of a ship can be found accurately there is no difficulty in applying the correction. In a seaplane the wetted area is not known even approximately. Calculations based on a conservative estimate of the wetted surface suggest that the whole of the resistance is frictional! The lecturer said that he had referred to the importance of measuring the wetted area in the lecture.

Group Captain Miley and Mr. McKinnon Wood both doubted whether the porpoising was necessarily associated with vertical motion. The lecturer said that he could imagine no better method of testing this contention than that of fixing the vertical position of a model which porpoises and seeing whether the model still porpoises. In all he had seen four models tested in this way. Two of the models porpoised, one very badly, when free to move vertically. They were quite steady when the vertical position was fixed. The lecturer was still convinced that the porpoising of seaplanes was essentially associated with the vertical motion.

The second point raised by Group Captain Miley was that recent tank tests had shown a certain seaplane to be stable and that the seaplane was unstable full scale. The lecturer did not know of any such seaplane and thought that the results of recent tank tests in which the wing and tail surfaces were fitted to the model and in which an attempt was made to get the moments of inertia correct should be more accurate than those of former tests.

In reply to Mr. Gouge, the lecturer said that one of the models whose resistance is shown in Fig. 14 is the same as that whose resistance is shown in Fig. 1, but the resistances are given for different attitudes in the two figures. He would not like to say at present which tank gives the nearest approach to the full-scale resistance. He was very interested in Mr. Gouge's theory that the resistance full-scale does not reach the maximum value because the motion is accelerated.

The lecturer said that the area over which large pressures, of the order of 14 lb./sq. in., occur simultaneously is very small. The area of the diaphragm of the D.V.L. instrument is about 3 sq. in. He did not know the area of the piston of the original N.P.L. instrument.

In reply to Major Penny's suggestion that useful information might be obtained by measuring loads on large-scale models, the lecturer said that so far as the loads are dependent on the hull shape and independent of its structure, it might be possible to determine the total loads on the model hull by measuring the deformation of the undercarriage struts. It is assumed that the float is attached to the fuselage by an ordinary undercarriage and not a resistance measuring one.

Captain Nicolson referred to tests of hydroplanes which showed that modifications made to eliminate porpoising caused an increased resistance. The lecturer said that this unfortunately was the usual experience. He hoped that future research would enable stability to be obtained without an increase in resistance.

The lecturer agreed with Captain Nicolson and Sir A. V. Roe that refuelling

in the air was an important problem which required further development. A good deal of work had already been done, both in America and in this country.

He thanked Mr. McKinnon Wood for his compliment upon the accuracy of the results of resistance measurements. He felt that the congratulations ought to be given to Mr. E. T. Jones, who was responsible for the measurements, a very fine piece of full-scale work. He was interested in Mr. McKinnon Wood's remarks on the effects of the interference of the sides and bottom of the tank on the resistance. Tests on these effects were at present in progress at the R.A.E., and the situation as far as tank interference was concerned would be much clearer when the results of the tests were available. He agreed with Mr. McKinnon Wood that the values of resistance derivatives would depend upon the frequency of the oscillations.

In reply to Mr. McKinnon Wood's comments on the size of models which could be used in a tank, the lecturer thought that the resistance at the higher speeds depended upon both the wave making and the frictional resistance and that no simple law could be applied in passing from model to full-scale.

In reply to Mr. Lower, the lecturer said that the resistances in Fig. 14 were calculated by assuming the lift appropriate to the angle of the hull. The attitude for which the resistance was calculated was actually smaller than that taken up in the model tests, but the resistance was reduced and not increased, as Mr. Lower suggested, by the change of attitude.

Captain Hill had affirmed that one could not fairly use the same type of aircraft for testing the relative merits of stubs and wing-tip floats. Mr. Garner did not think it was essential. The problem as he visualised it would be to ask the same designer to produce to a definite specification two aircraft—one fitted with stubs and one with wing-tip floats; and he would be allowed a certain amount of discretion in deciding on the type of aircraft to which the stabilisers should be fitted. The remarks on the effect of loading over a short period were very interesting to him; he did not know that any such experiments had been made.

Mr. Pye had asked if the question of altering the angle of the stub wings in the air had ever been considered. The lecturer had discussed it a good many times with designers and they all said the mechanism would be very heavy. Nevertheless, he thought that it was a point to which practical demonstration might be given.

He agreed that a correction depending on the drag of the nacelle would have to be applied to the thrust meter reading in order to get the net thrust, but thought that the correction could be determined sufficiently accurately from wind tunnel tests such as those in R. & M. 1239. Reverting to Mr. McKinnon Wood's question, one might say that one reason for the accuracy of the results obtained in the indirect method for the III.F. was that they had a piece of apparatus by which they could determine accurately the static thrust of the whole aircraft.

In reply to Mr. Korvin Kroukovsky, the question of the rigidity of twin float gear is one of the structural problems outside the scope of the lecture. He agreed that lack of rigidity is a frequent fault, very often caused by lack of complete bracing in the float gear. Cross bracing wires connecting the ends of the booms, although redundant members, are certainly necessary to secure rigidity. It is not sufficient to rely on the rigidity of the boom attachments to the floats to prevent torsion. It is often found, too, that each float is able to twist about its own longitudinal axis. The remedy is, of course, more rigid float attachments.

The results of many tank tests in this country show that the effect of making the vee of a hull steeper is to increase the resistance, other things being equal. The results obtained by the Edo Aircraft Corporation on floats with different angles of vee are the only ones he had heard of which show a reduction of resistance when the vee is made steeper.

AIRCRAFT IN RELATION TO PETROLEUM TECHNOLOGY: USE FOR SURVEY AND TRANSPORT*

BY

H. HEMMING, A.F.C., F.R.G.S., A.F.R.AE.S.

INTRODUCTORY

The lecturer has been concerned with commercial air survey operations since their inception after the war, more on the organisation, finance and business side, rather than on the technical. It is therefore from the angle seen from the directing side that this paper is submitted. As certain technical aspects will be of interest to the Institution, they are referred to, in order that attention may be drawn to them. Through the courtesy of the firms responsible for manufacture, certain apparatus is exhibited which includes an air camera, the automatic pilot, and the contouring stereoscope. Certain technical experts have kindly promised to be available to answer questions or to demonstrate apparatus, and certain individuals and firms have been good enough to lend photographs and slides. Acknowledgment for such assistance will be made in the reply to the discussion.

Those who wish to be more fully informed on the technical aspects of air survey would be well advised to study some excellent technical papers that have been read recently. These will be referred to later. As aircraft can be of great service for the rapid transportation of personnel and equipment in connection with oil-field maintenance and development, that side is also touched on.

GENERAL

The whole subject may be divided into two main sections, viz.:—

(1) Aircraft as a means for rapidly obtaining information of technological value.

(2) Aircraft as a means of transporting personnel or material from one place to another.

The first section is dealt with as follows:—

Section 1 *Survey.*—Air surveying provides a means of obtaining information of technological value and may be subdivided into:—

(*a*) Visual reconnaissance.

(*b*) Photographic surveying.

It is submitted that both of the subdivisions should be of interest to the petroleum technologist and more especially to the following:—

The Oil Geologist, in obtaining information regarding major and minor land-forms, rock outcrops, faults, colour of residual soils, vegetation and plant ecology in relation to geology and geological mapping. (See Figs. 1 to 5.)

* Paper read before the Institution of Petroleum Technologists, and reprinted by permission from the Journal of the Institution, Vol. 19, No. 112, February, 1933.

The Oilfield Engineer, in obtaining data, which may be of great economic importance in the selection of pipe-line routes, field railways, sites for camps, roads for transport of drilling equipment and field supplies, sites for tank farms, pump stations, field telephones, supply of timber for construction purposes, and the available inland waterways.

The Marine Engineer, in obtaining information relating to coastal topography, suitable sites for sea loading stations, submarine pipe-laying, bars

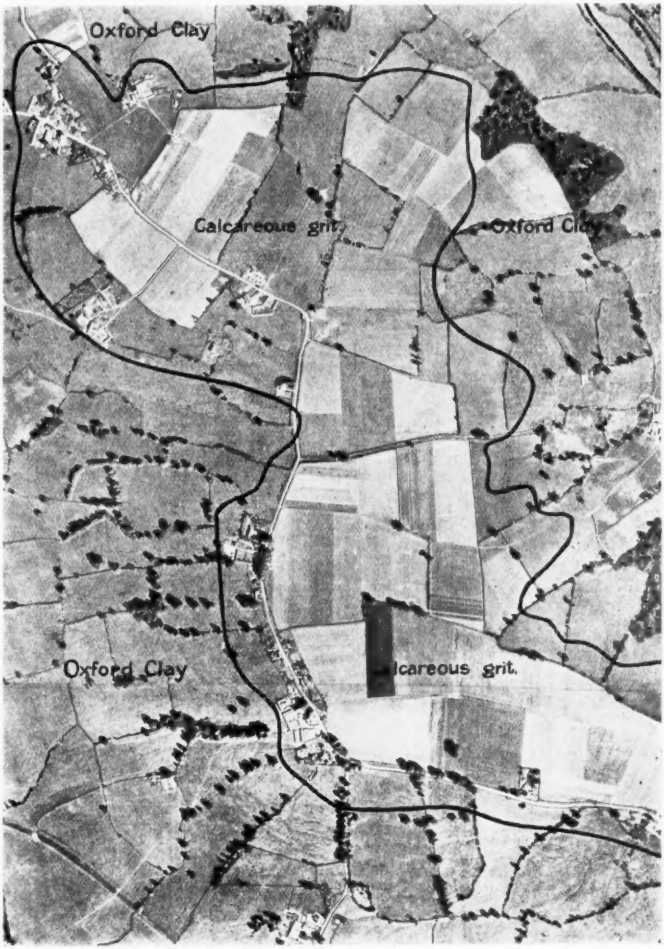

FIG. 1.

Geographical characteristics of Spirthill, Wiltshire.

The geological boundary marked has been transferred from the geological map of England and makes an interesting comparison with the boundary as shown by surface features on the air photograph.

—*Courtesy of The Aircraft Operating Co., Ltd.*

at river mouths, dredging requirements, existence of currents, and general hydrographic data.

Air Surveys made for the Oil Industry.—Unfortunately, the British companies who carry out air-survey operations have done little serious work for the British oil companies; a certain amount has been done by foreign operators. The great oil industry of the Empire has not yet appreciated that it may secure very considerable benefits from having air surveys made.

For actual experience in the successful application of air surveying to oil-field development, it is necessary to turn to the United States of America. In that country, air surveying has become a recognised branch of the art of the oil-

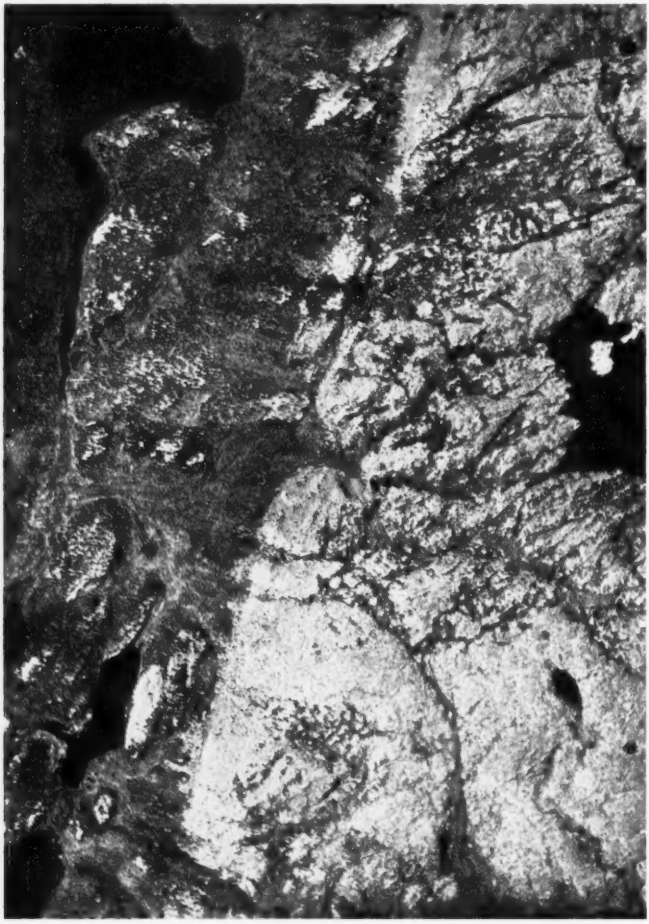

FIG. 2.

Vertical photograph in North-West Territories, showing fault.

—Courtesy of Major B. Day.

field engineer and of the oil geologist. It is unfortunate that this admission has to be made, for in every branch, other than that at present under discussion, we can quote concrete examples of the success attained by the British operating companies. The results at present being obtained in Africa by certain mining

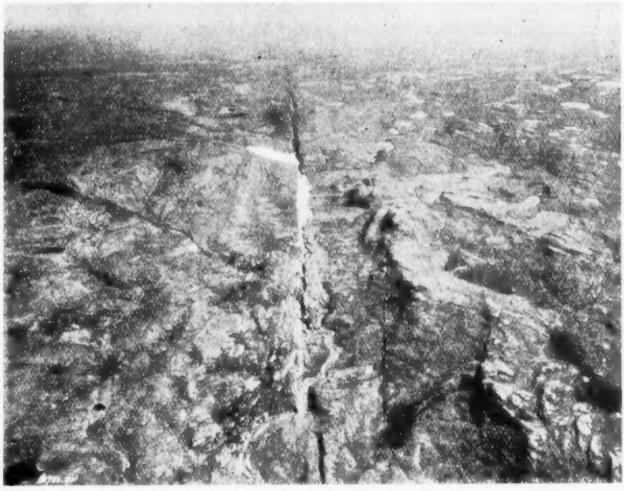

FIG. 3.

Oblique photograph in North-West Territories, showing fault.

—Courtesy of Major B. Day.

FIG. 4.

Quartz outcrop in North-West Territories.

—Courtesy of Major B. Day.

companies, using air survey methods for prospecting, show very great promise indeed.

Recently, Mr. Donald Gill read a paper before the Institution of Mining and Metallurgy on " Aerial Survey in Relation to Economic Geology."* That paper marks an important forward step in the progress of air surveying and undoubtedly forms an authoritative treatise on the geological aspects of the subject, and should be a standard reference and guide for some time to come. Mr. Gill's paper includes a most useful bibliography, which has been used extensively in the compilation of the present paper.

FIG. 5.

Photographic mosaic of Echo Bay District, Great Bear Lake, North-West Territories, Canada.

—*Courtesy of Major B. Day.*

* Reprinted in JOURNAL for March, 1933, pp. 227-287.

Attention is drawn to Mr. Gill's paper, where he refers to the practice of " Aerial Geology " in the United States, mainly in connection with oil-field development, and to section III of the bibliography, where Mr. Gill refers to the considerable amount of American literature on the matter.

In dealing with his subject Mr. Gill says that " Aerial Geology " is a very new geological tool. Its commercial use in the United States appears to have been confined to prospecting for oil in California and Texas. Air surveying is used extensively by the United States Geological Survey for the preparation of topographic base maps. The use of air survey methods by the oil companies has, naturally, been confined to certain areas of sedimentary rocks for ascertaining the position, nature and extent of oil structures, and tracing sedimentary horizons. In California, the air photographs have located previously unknown faults in areas that have been closely geologised on the ground.

Mr. Gill states that the saving in time in conducting an examination by using air survey methods is put as high as from 50 to 80 per cent., due to: (1) The speed with which the contact prints can be delivered (as against the preparation of a topographical map), and (2) the time saved in the field by having much of the normal work of mapping appearing already on the photographs, which helps in self location and gives the advantage of the " air view." Further claims are: (3) Secrecy, since much information can be obtained without having to set foot on the ground. (4) The improvement in the quality of the field work when working with photographs. (5) The excellence of mosaics for illustrating office conferences. The lecturer would add a further claim, that is the value of stereoscopic examination of the air photographs both in the office and on the prospect.

A most interesting series of illustrated articles, dealing with " Air Survey in Relation to the Oil Industry in Texas," appears under the name of Jack Logan in *The Oil Weekly* from January to February of 1932 inclusive. In dealing with the use of air maps to geologists one article says that: " Using the aerial survey as a reconnaissance or source map, the geologist finds upon it a wide variety of significant data. Anticlines, domes, faults, formation contacts, isolated exposures, and other geological conditions of importance are manifested through stream patterns, dipping beds, colour changes in soils or differences in vegetation due to variations in soils."

In another article the same writer, in dealing with " The Location of Pipe Line Routes by Aerial Photography," says: " So effective is the photographic map, indeed, that in many instances its cost is immediately returned or more than offset by savings on materials and construction work made possible by the shorter and better located route, to say nothing of the ultimate economies in operation and maintenance costs." The reasons given for this are:—

1. Transport and stringing costs can be estimated better, because highways and railroads are prominently shown.
2. Stream crossing expenses can be estimated more accurately.
3. Obstacles, such as high hills, or precipitous stream beds in rough country, and farm houses or towns in flat country, can be studied advantageously in advance.

The saving claimed for the company or the contractor using air survey methods is said to be conservatively estimated at twice the cost of the air survey in every 100 miles of line. This saving is gained through the avoidance of difficult topographical features on the pipe-line route.

According to *The Texas Star,* the house organ of the Texas Pipe Line Company, at least half a million dollars alone in material and construction work was saved by having an air survey made of the route for a crude oil pipe line from Pecos County, West Texas, to the Gulf Coast.

An interesting example of the use of the air photograph for obtaining data for determining the general route of a proposed adhesion railway to follow up a forest clad Serra in South America may be of interest. The precipitous and broken country, covered with matted jungle, made it quite impracticable for the survey to be made on the ground. In fact, it was extremely difficult to obtain the necessary control and spot heights for the making of the plan and the drawing in of the contours from the air photographs.

In referring to the work after completion of the air survey, the General Manager of the Railway wrote to the British operating company responsible for the work and said that the survey had provided all the information required to allow of a decision that the alignment and construction of an adhesion line with a maximum 2 per cent. grade was possible in a distance of 41 kilometres. He also stated that owing to the difficulty of the ground, it would have required the employment of several field parties to obtain the same information, that it would have taken a much longer time to complete the survey, and would have cost at least eight times as much as the air survey.

This example is given because, although the work was not carried out in connection with oil-field development, it is believed that some of the problems involved are similar to those met with in oil engineering.

There is a special application of air surveying which is of interest to the oil-fields engineer, when working in territory where accurate maps of the district are not available. An air survey of the district will enable any existing maps to be both rapidly and accurately revised. A study of the revised map and of the relative air photographs should enable boundaries to be delineated, and show the relationship of selected plots of territory to others, in view of possible offsetting by competitive interests. In areas of which no maps exist, the use of air photography enables a map to be made far more rapidly than would be possible by using ground survey methods only. As already indicated, in addition to providing much data for mapping purposes, the air photographs at the same time record data relating to the economic resources of the area surveyed. For instance, in a recent air survey made in the United States for road development, it was found by chance that the air photographs contained geological data of great importance to the oil industry.

It must be emphasised that air photo-surveying is not competitive with ground surveying. The aircraft merely provides the surveyor with a platform which enables him to view country normally inaccessible to him, except at great expenditure of time and money, while the air camera faithfully records all and even more than he can see.

All air surveys depend for their accuracy on a ground control, if the data from the photographs is to be turned into map form, or if a rectified mosaic is to be made. It is also necessary to interpret a considerable number of photographs on the ground. It may be said that in all cases the air photograph considerably speeds up ground survey work; in many cases it reduces the cost of the work, and if value is to be given to all the other information obtainable from the air photograph in connection with geology, ecology, forestry and of the general resources and condition of the country, then there is no doubt whatever that an air survey is in general far more economical than a purely ground survey.

In the realm of geology, aircraft and the air camera can be of great assistance to the geologist and the engineer. Close prospecting, however, must always be done on the ground; but by means of air reconnaissance and by studying the air photographs the geologist can obtain valuable indications as to where to prospect and how to get there by the easiest route.

All those concerned with any new enterprise have to go through a period of discouragement by vested interests, and those concerned with the development of air surveying are not yet out of the wood in this respect. Sufficient work has been carried out, however, to enthuse a number of geologists, surveyors and

others, and no doubt the day is not far distant when every geologist and surveyor will have to have a general knowledge of air surveying if he is to be considered as fully qualified in his profession.

The Development of Air Surveying.—During the war, air photography proved to be of the greatest value in confirming and recording artillery shoots directed by air and ground observation. It was also extensively used for rapid map revision, particularly in relation to trench maps, and for spotting hostile battery positions, as well as for giving indications of movements of troops and of munitions. A French authority, André Carlier, President of the French Aerial Association, has stated that, during the last years of the war, 80 per cent. of the information about the enemy was due to air photography.

After the war no time was lost in adapting aircraft and the air camera to peaceful pursuits, and in this respect the Canadian Government showed great initiative. Apart from encouraging private enterprise, the Canadian Government used their Air Force for photographing undeveloped and unmapped areas and also surveyed and valued large areas of forest by this new method. To-day, some 640,000 square miles of the Dominion have been mapped by air survey methods, and aircraft are also used for transportation work in connection with the development of new areas as well as for forest fire patrol work.

The Report on Civil Aviation for the year 1931, issued by the Dominion of Canada Department of National Defence, states in its introduction that: "Air transport in the far North shows great activity. The discovery of important mineral deposits in the North-West territories is directly attributable to flying. Without aircraft, these discoveries and their development would have hardly been possible—the application of aerial photography to mapping and the use of air transport by the Survey Services has been on a wider scale than ever before." These Canadian reports are well worth studying.

In a letter to Mr. Gill, the Director of the Geological Survey of Canada, in referring to air surveying in the Dominion, states that:—

> "The contacts between different formations can, in places, be recognised and transferred with complete precision from the photograph to the map. The photograph frequently shows faults and other geological structures much more clearly than these structures could be recognised on the ground. This appears to be due to the fact that an observer has anywhere from two square miles to ten square miles of country under his observation at one time in a photograph, whereas on the ground his observation is usually limited to a radius of a few hundred feet or yards. We have a considerable number of cases in which geological structures are visible in photographs that could only be worked out by ground methods in a period of days, weeks or even months, and even then not so satisfactorily."

A further letter from the same source states that the air photographs yield four kinds of information in the pre-Cambrian areas as follows:—

1. Boundaries of formations, after a few preliminary traverses on the ground.
2. Faults, usually indicated by a change of relief when viewed stereoscopically.
3. Long and sometimes complexly curved strike-lines in the crystalline sediments. These prove very useful in working out the structure; and
4. Boundaries of the drift-covered areas, which are very precisely defined.

It will be seen, therefore, that good progress is being made in Canada in the application of air photography to geology and mapping.

The first air surveying expedition to leave the British Isles was sent out under the leadership of Major C. K. Cochran-Patrick, D.S.O., M.C., in March, 1921, by a company of which the lecturer was a founder, to make an air survey

of part of the Orinoco delta for an oil company. Deltas are notorious for their unsatisfactory weather conditions at certain times of the year, and unfortunately the wrong time was chosen for the expedition to start its operations, so that the survey was not a success. Those concerned with the work however realised, from the experience gained, that air surveying would one day play an important part in economic development of territory. In spite of past and present difficulties all the key men of that early expedition are still actively associated with the carrying out of air surveys.

Most of the work in the Empire, with the exception of that in Canada, has been carried out by two British companies—the Aircraft Operating Co., Ltd., and the Air Survey Co., Ltd. These companies between them have to date made air surveys, both photographic and reconnaissance, of areas covering in total approximately 200,000 square miles. The whole of this work has been financed by private enterprise unaided by any form of Government subsidy, and covers areas in Africa, India, Burma, Iraq and South America. It is submitted that this is a very remarkable achievement for unsubsidised private enterprise.

Methods Employed.—It is not proposed to describe the methods used in detail, as that has been dealt with by Major C. K. Cochran-Patrick in his paper on "Present Practice in Aerial Survey," which he read before the Society of Engineers in October, 1931. An interesting paper also dealing with air survey methods was read before the Royal Aeronautical Society on December 8th, 1932, by Lieut. J. S. A. Salt, R.E. The various methods used are also fully referred to in Mr. Gill's paper.

Visual Reconnaissance.—Visual reconnaissance from the air is often a preliminary to a survey by photographic methods. By qualified experts making a reconnaissance flight over an area, it is often possible to eliminate large parts of the area from close survey. In Canada, areas of unpromising country have been eliminated from close prospecting by this means. In Canada, India and Burma forest stocking maps have been prepared by means of visual reconnaissance and sketching. The value of visual reconnaissance for geological work is dealt with in Mr. Gill's paper.

Photographic Surveying

There are two methods in use: (1) The vertical method; (2) the oblique method. They are described as follows:—

1. *The Vertical Method* is the one which is most likely to interest the petroleum technologist, for the photographs are taken as near to the vertical as is possible and so provide a pictorial map of the ground. In using this method, the area is flown over in such a manner as will ensure that it is covered by parallel strips of vertical photographs, the individual photographs of which overlap each other in a fore and aft direction by some 50 to 60 per cent., and in a lateral direction by some 20 per cent. The height at which the photographs are taken may be from 10,000 to 15,000ft. more or less, according to the scale required and the lens used. The flying speed may be taken at 100 m.p.h. It will be appreciated that very accurate flying is necessary for air survey purposes, for the aircraft must be maintained at a constant height and flying speed, and kept in perfect trim, so as to reduce distortion on the photograph, due to tilt, to the absolute minimum.

Gyroscopic control has been recently introduced and is reported to have given some remarkable results. It has not yet however been tried out on any large air survey contracts so far as the lecturer knows, and development in this direction is awaited with much interest.

The overlap between the consecutive photographs enables that part of the area common to the two photographs to be examined in the stereoscope; by this means the ground may be seen standing out in perspective, and thus affords the

geologist a most efficient means of viewing detail, as seen from the air, in vertical as well as in horizontal relation to other detail. The lateral overlap between strips is made so as to ensure that no gaps are left in the area photographed. By using a special contouring stereoscope it is possible to draw in form lines on the photographs and contours where sufficient spot heights are available.

The photographs can be pieced together so as to form a mosaic or picture map, or the topographical data can be transferred from the photographs and put into map form. In cases where no triangulation exists, this will be provided by the ground survey parties, who will use the air photographs in order to find their way about the area and to select suitable control points. The distance apart of these controls and the method employed to establish them depends on the scale and accuracy required for the maps or mosaics, as well as on the nature of the country.

For maps on scales up to 1/50,000 (1.26in. = 1 mile) the vertical system of mapping is used. This method is also essential when the air survey is required for pipe-line construction. In the States the scales chiefly used for geological work are said to be those of 2,000 and 1,000ft. to the inch, that is (1/24,000 and 1/12,000 respectively). For town planning purposes mosaics have been made on as large a scale as 1/1,000 (63.36in. = 1 mile). In Africa the best scales for geological interpretation have been found by experience to be: (*a*) 1/10,000 (6.33in. = 1 mile) for large areas and (*b*) 1/5,000 (12.67in. = 1 mile) for the close examination of small areas.

2. *The Oblique Method* has only been used successfully for mapping large areas of comparatively flat country in Canada and in Northern Rhodesia. Where small scales are required of the order of 1/250,000 (3.94 miles = 1in.) this method is particularly useful, as it is both rapid and economical. By it, 65,000 square miles of bush country were mapped in Northern Rhodesia, the photography being completed in three months and the drawn maps being delivered within another fifteen months. (See Fig. 6.)

In the Rhodesian survey, in order to provide the control, parallel strips of verticals were run across the area in an east-westerly direction, the distance between each strip being thirty miles. Parties of ground surveyors then marched along the lines covered by the strips, using the actual photographs in order to find their way. At thirty-mile intervals, suitable control points were established by selecting detail of a permanent nature, which showed up on the photographs, and then establishing its correct position by means of astronomical observations and wireless time signals.

While this work was proceeding the flying party flew across the area in parallel lines running north and south, approximately 10 miles apart, taking oblique photographs at an angle of 90° to the line of flight, alternatively to port and starboard, at such intervals as would ensure that the consecutive photographs overlapped each other. These photographs were taken at an angle of depression sufficient to include the horizon on the top of the photograph. Perspective grids were then constructed in the drawing office, and by applying these grids to the photographs the mapable detail was drawn in in plan form. This operation is explained in Major Cochran-Patrick's paper already referred to, and is dealt with in detail by Mr. W. Norman Roberts, in the Journal of the Royal Aeronautical Society of June, 1932, under the title of "Aerial Surveying in Northern Rhodesia."

To the uninitiated, the oblique photograph is easy to read, as it gives a view similar to that obtained from a high hill. These photographs will undoubtedly supply the geologist with a general idea of the nature of the country, but for the close examination of areas prior to prospecting the vertical photograph is necessary.

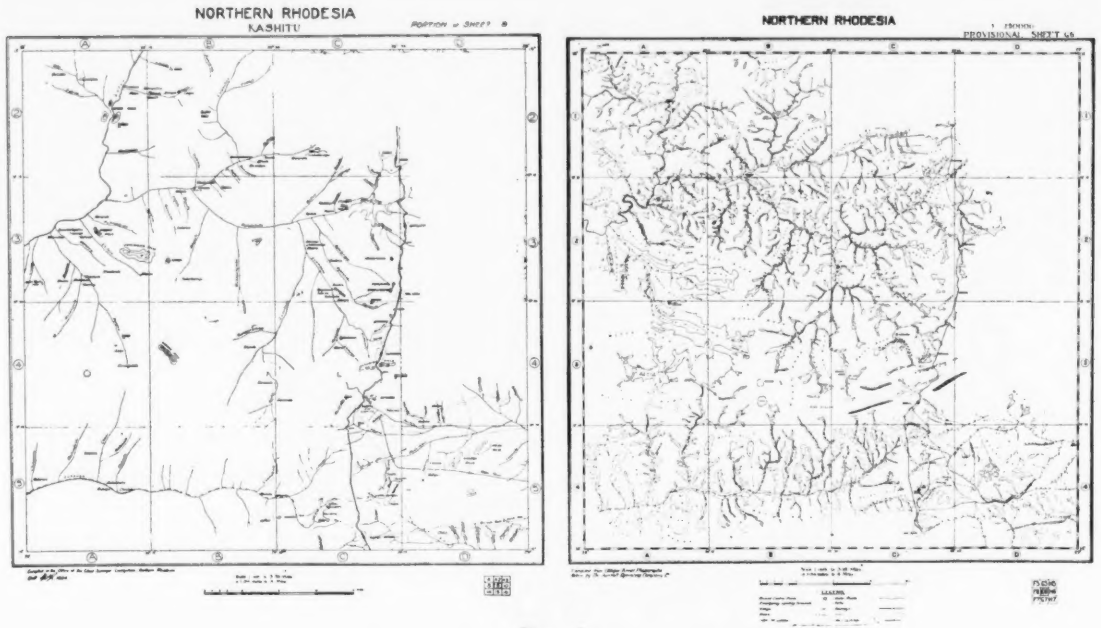

FIG. 6.

Part of Northern Rhodesia, showing on left old Government map and on right same map prepared from air photographs.

—Courtesy of The Aircraft Operating Co., Ltd.

Economic Surveys.—Where an economic survey is to be made, geologists, ecologists, forestry and other experts as required would go into the field with the ground control parties. They would interpret the detail as seen on the photographs by checking on the ground. For this purpose areas would be selected on account of their easy accessibility. With the knowledge gained, the photograph may be indexed and then used for the interpretation of detail of the remote or inaccessible areas, which have detail similar to those areas already investigated on the ground. (See Fig. 7.)

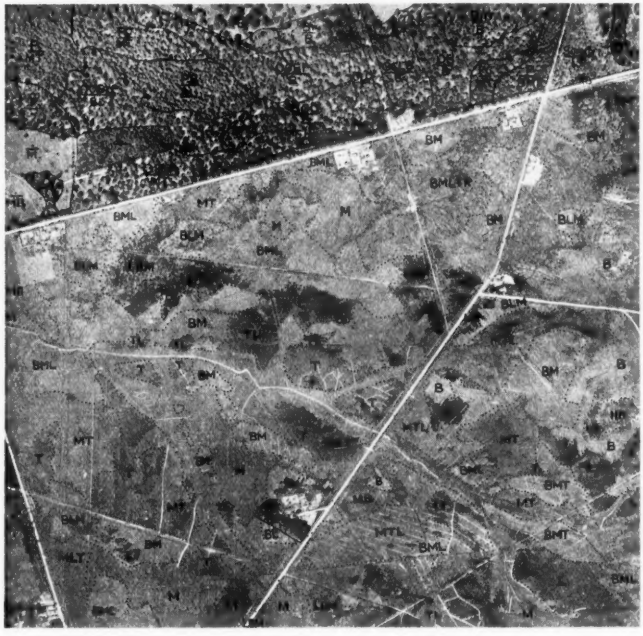

FIG. 7.

Example of interpreted and indexed photograph.

Boundary of Forest Type ——

Tree Species: O = Oak; B = Beech; Bi = Birch; S = Spruce; C = Spanish Chestnut; L = Larch; P = Scots Pine.

Boundary of Soil Flora .....

Soil Flora: B = Bracken; L = Ling (Calluna vulgaris); H = Heath (Erica Cinera); T = Bell Heather (Erica tetrahelix); M = Mollinia and associated grasses; R = Rubus spp.

N.B. In the forest the principal tree species are shown over the line and the general soil flora type below.

In a mixture the order in which the species are shown does not indicate so much their numerical frequency as their apparent dominance.

—*Courtesy of The Aircraft Operating Co. Ltd.*

In assessing the value of air surveying, therefore, it is important to remember that a great deal of this information relating to the economic resources of the country may be obtained, although the main object of the survey may be for mapping purposes only.

Mr. R. Bourne has done a great deal of valuable pioneer work in the application of air survey to economic development, and another authority is Capt. C. R. Robbins. Mr. Gill refers to their various papers in his bibliography.

Co-ordination of Interests.—The diversity of interests that can be served by an air survey calls for some method of co-ordination, so that all may obtain the benefits of the survey at a minimum of cost. Mr. Salt, in his recent paper, advocates the formation of an Imperial organisation to deal with the work under the control of the Government. Previous to Mr. Salt's paper, the lecturer had submitted proposals to the various Government Departments for the creation of an Imperial organisation which would be independent of Government control. As those proposals are still under consideration, they will not be referred to further at this juncture. Both proposals were debated and are reported in the discussion of Mr. Salt's paper.

In the lecturer's opinion the maximum benefits can only be secured from air surveying if really large areas are surveyed—this implies co-ordination of interests. The photography can be completed so rapidly that only a comparatively few special air survey aircraft would be required. These could be located at suitable bases and sent from one contract to another, so as to take advantage of the most suitable weather conditions. Weather plays a most important part in air surveying, for clear skies are essential to the making of clear photographs. As several months' work on the ground may be provided in a few hours' flying, it is essential that the right time of the year is chosen for the work. By having a sound scheme of co-ordinated interests the survey aircraft could be switched from one area to another as dictated by weather conditions, instead of piling up cost in idleness on the ground. For example, in Rhodesia the area of 65,000 square miles was photographed in 50 flying hours, then the aeroplane was available for other work, yet the rest of the work on the ground took 15 months to complete.

There are always, of course, cases where a company desiring a small survey may be able to use some local organisation, and much useful work has been accomplished in this way already. But to secure the economic mapping of the Empire, a matter of great importance, as nearly four-fifths of the Empire is inadequately mapped, some co-ordinated plan on Imperial lines seems to be desirable.

The curtailment of survey programmes as a measure of economy is in actuality a means of causing grievous waste at some future date. The late Sir Gordon Guggisberg, when speaking at a paper read by the present lecturer some five years ago, gave a striking example of waste due to lack of survey. He stated that "one and a half million pounds had been spent" in straightening out the railway between the coast and Coomassie Gold Coast; continuing, he said: "If you can get a photographic map first, you are going to save yourself literally hundreds of thousands of pounds in road and railway construction; but if you are going to conduct that survey by working through forests, you are going to take a very long time."

Equipment Used by the British Companies

Aircraft.—To-day aircraft for survey may be considered in classes:—

1. Light aircraft for the survey and reconnaissance of small areas, at moderate altitudes, or of areas where long duration of flight, and of maximum security from forced landings is not an essential. The DH. Moth type has proved to be well suited for such work.

2. High performance single engine type to be used where good range and high ceiling is required. An example of this type is the Fairey 111 F. which,

fitted with floats, was used recently by the Air Survey Co., Ltd., for the survey of swamp areas in the Sudan and Uganda.

3. The multi-engine type for surveying large areas of unexplored and difficult country where maximum range, ceiling and reliability is a first consideration. As air surveying finds its greatest scope in dealing with large areas of little known territory, it is proposed only to describe this last type.

Costly experience showed that the ideal aircraft should fulfil certain requirements, of which the following are of particular importance: (1) Maximum reliability; (2) long range; (3) high performance; (4) uninterrupted view for the pilot forwards and downwards to the vertical and also to each side; (5) comfortable cabin in which the observer or photographer could work; (6) alternate positions for oblique and vertical cameras, situated where parts of the aircraft would not mask the view; (7) easy control for accurate flying; (8) suitable construction to enable the aircraft to weather extremes of climate.

It was only by having an aircraft with these characteristics that the area of 65,000 square miles in N. Rhodesia could be surveyed with safety and efficiency. Mr. Alan S. Butler, the Chairman of the Aircraft Operating Co., realised this, and had the machine built by the Gloster Aircraft Co., Ltd., at his own expense.

The machine is of biplane construction with the pilot located right in the nose. It is equipped with two Bristol Jupiter X 1 type engines giving a maximum of 500 h.p. each. On its official trials the machine did a full-out speed, while flying level at 19,000ft., of 121 m.p.h., its cruising speed being 108 m.p.h. with full survey load. The maximum range at cruising speed with full load was found to be 800 miles. Height could be maintained on one engine up to 9,000ft.

Special attention was given to refuelling and to the fitting out of the machine for survey purposes. The then Secretary of State for Air, the late Lord Thomson, accompanied by the then Under-Secretary, Mr. F. Montague, went on the first official trial flight, after which it was flown out to Africa by Mr. Butler, and immediately used for the survey referred to.

The Air Camera.—The camera used by the British operating companies in their recent work is known as the Eagle type 1, and is made by the Williamson Manufacturing Co., Ltd. It is constructed throughout of metal and can be fitted with lenses of focal lengths varying from 6in. to 20in., according to requirements of scale.

When fitted with a 7in. lens the weight of the camera and accessories works out approximately as follows:—

Camera, complete with motor and control ...	55	lb.
Battery	20	,,
Camera mounting	13½	,,
One charged magazine	14	,,
	102½	,,

Roll films are used, each roll containing one hundred exposures. The available area on each negative for the photograph measures 7in. by 7in., and there is a margin to one side for the photographic record of an instrument panel, which is incorporated in the camera. The data secured for each exposure by photographing this panel consists of: (1) The aneroid height at time of exposure; (2) the time at which the exposure was made; (3) the bubble position on the fore and aft spirit levels; (4) the serial number of the negative; and (5) information written on a small plaque relating to the type of lens used, the nature of the job and any other relevant information which may be written thereon.

Some idea of the area covered with different lenses from 14,000ft., on a 7in. by 7in. negative, will be gathered from the following table:—

Focal length of lens.	Area covered.
7in.	14,000 ft. sq.
8½in.	12,000 ,,
10in.	9,700 ,,
20in.	5,000 ,,

Films are carried in metal magazines and may be changed rapidly between exposures, while the survey is in progress. The number that can be carried is only limited by requirements or by the capacity of the machine, having regard to other load.

The camera is automatic in action and is normally driven by a small electric motor. A wind motor may be used, or the mechanism may be operated by hand.

The operation of the camera is controlled by a remote control situated in the pilot's cockpit, or in any other convenient spot in the aircraft. It consists of (1) a switch to control the driving motor, (2) a press button to enable exposures to be made independently of those timed for overlap, (3) a dial showing the number of exposures made, and (4) an intervalometer, by which the camera may be set to take photographs automatically at any desired interval of time between 5 seconds and 60 seconds. In addition, a red light is located in the pilot's cockpit, which is automatically switched on a few seconds before each exposure is made, so as to warn him to steady on his course.

The camera is mounted on a special mounting, which is provided with a suitable shock-absorbing device, in order to damp out vibration. It can be rotated so as to allow for drift, and pivoted so that the camera may be kept in a vertical position. The mounting used on the Rhodesian survey was the Eyrie type; this has the advantage of being adjustable for oblique photography. It is 18½lb. heavier than the Eagle mounting, but this extra weight is well made up for by its increased usefulness.

Until recently a roller blind shutter was used, but now the camera makers have produced a Louvre shutter, which works on the venetian blind system, *i.e.*, with moving slats. This new shutter is located just behind the lens, and by its use shutter distortion has been eliminated, while even illumination of the negative is secured. The shutter has high efficiency and, being made entirely of metal, it is unaffected by climate.

In order to secure good colour values Panchromatic films are used. The development of " infra-red " photography is being watched with considerable interest, as its successful application to vertical photography, if that be possible, should greatly extend the use and value of air photography for geological work, because the range of colour values obtainable will be increased. " Infra-red " photography, if successful, should also enable flying costs to be reduced considerably, by making it possible for photography to be carried out under atmospheric conditions which are not possible when using panchromatic film and the special filters used at present.

These special filters (type K 2 and K 3) are used in order that haze due to the moisture content in the atmosphere may be penetrated. It is not possible to cut out haze due to smoke or dust, so that it is important to ensure that the best time of the year is chosen for air photo operations. Clear skies and air are essential for good results.

A lighter type of air camera, the Eagle type 3, is also marketed by the same makers for use in light aircraft for work over small areas of accessible territory. Its weights work out as follows:—

Camera, complete with motor and control ...	33 lb.
Battery	20 ,,
Camera mounting	4 ,,
One charged magazine	7 ,,
	64 ,,

The size of the negative for this smaller camera is 5in. by 5in.

Operations in the Air.—A brief description will now be given of the operations in the air on an air survey flight. When at photographic height, say 14,000ft., the pilot finds the speed and direction of the wind by means of his wind gauge bearing plate. With this data the photographer works out the intervals that he must allow between exposures, so as to secure a 60 per cent. overlap, and sets the required interval on the intervalometer on the remote control. The pilot meanwhile flies towards the starting point for the first strip, on the bearing he is to steer on. He settles down to a steady course and speed. Looking ahead, he picks up leading marks, for by steering on leading marks he can instantly correct for local changes of wind. A compass will not enable him to do this, though, of course, the pilot is checking his course by compass all the time. When vertically over the starting point the observer switches on the camera; immediately the first exposure is made, and then the camera motor winds the film ready for the next exposure and resets the shutter. A few seconds before the time due for the next exposure the red light goes on and warns the pilot to steady on his course, then the next exposure follows, and so the process is repeated throughout the flight.

Flying for air survey requires particular skill, for in addition to the need for accurate navigation, the machine must be kept at a constant air speed and height, and tilts must be kept to as small an angle as possible. With reasonably good flying tilts should not exceed two degrees. It should also be remembered that probably the pilot is flying over completely unmapped country, therefore he nas to memorise features to the side of his next overlap, so as to provide a check on his return strip, for gaps in photography mean a reflight of that part of the strip and would be very costly. Although the automatic gyro control may prove to be of great value for air survey flying, the pilot will still have to be a highly skilled individual. In certain classes of work the crew of an air survey aircraft may be in the air for as much as six hours or more.

Operations on Ground after Fight.—The films are developed in special tanks as soon after the completion of the flight as possible. They are then dried on a drum and after that contact prints are run off in the contact printer. The prints are then strung together in their correct position and checked for overlap, so as to ensure that there are no gaps. After that the films are rectified and printed in the auto focussing enlarger to the scale required. The prints are then turned over to the drawing office for mapping purposes, and also issued to the geologist and others interested in their interpretation. Mr. Salt's paper and that of Major Cochran-Patrick describe the operations in the drawing office.

Cost and Time.—It is impossible to lay down standard costs, and it is even misleading to quote costs. Costs depend on the scale required of the prints, mosaics or maps; the size and nature of the area, its position, accuracy required and several other factors.

The following extract taken from Burma Forest Bulletin No. 11, deals with the air survey of the Irrawaddy made by the Air Survey Co., Ltd., under the direction of Mr. Ronald Kemp, in conjunction with the Burma Forestry Department. It is an official document, and provides an interesting comparison of the cost and time of ground and air methods respectively in connection with the particular problem involved.

"PART IV.—SUMMARY OF RESULTS.

Although the results of the aerial survey from each point of view have been given in the special reports, it may not be out of place to summarise them here from the Forestry Department point of view.

1. *Cost.*—The cost, including ground work and mapping, has worked out at about Rs.293.7 per square mile. A ground survey on the same scale would

have cost in the neighbourhood of Rs.500 per square mile, without giving any indication of the types of forest growth.

2. *Rapidity.*—The actual survey was completed in five months, and the whole period taken from the commencement of the fixing of the ground control to the completion of maps and stock-maps should not greatly exceed one year. Ground survey would have taken three to four years.

3. *Accuracy.*—This is far in excess of anything that could have been obtained by ground survey in this type of country, except as a further increase in cost and time.

4. *Details Available.*—The areas and distribution of the different types of forests are not only obtainable at no increase of cost, but with an accuracy that it would have taken years and a considerable expenditure to have equalled."

The survey of 65,000 square miles in Northern Rhodesia worked out at a cost of £1 per square mile. The Company had to do all the work, including the making of the maps to a scale of 1/250,000 and the laying down of the astronomical control. The whole operation was completed in eighteen months. A comparison cannot be given for ground survey cost in such country. There is no doubt that a ground survey could only have been carried out at an expenditure of time and money which would be prohibitive.

Among other factors, cost is controlled by the scale required, the size and nature of the area, and the type of information desired. Mr. Gill has estimated that a controlled mosaic could be made on a scale of 1/50,000 of 50 square miles at £30 per square mile. On such a small area the work could only be carried out at that figure if an air survey unit was in the neighbourhood.

The lecturer has estimated that 400,000 square miles of territory in South America could be mapped from vertical photographs to a scale of 1/50,000, with 25-metre contours included, for a cost which works out at £3.77 per square mile. The survey could be completed in five years. This shows that by going for really large areas costs can be considerably reduced.

In the lecturer's opinion it would be possible to make an economic survey by air methods combined with ground control and interpretation, of 200,000 square miles of bush country, similar to that in Northern Rhodesia, for a figure under £2 per square mile. The survey to include (1) the making of a reconnaissance map of the whole area on a scale of 1/250,000, (2) a drawn map on a scale of 1/50,000 of selected areas totalling 20,000 square miles, and (3) mosaics of these selected areas on a scale of 1/25,000. The whole work to be completed in three years.

The only comparative costs relating to air surveying for oil-field development that the lecturer has been able to find are contained in an article on "Aerial Photographic Oil Surveying," by Charles E. Kern, in the *Oil and Gas Journal* of July 16th, 1925. This writer says that it is understood that from $65 to $100 per square mile has been charged by private air survey companies for making surveys in heavily jungled terrain similar to that in Venezuela, whereas petroleum companies are paying about $260 per square mile for ground survey work in such country. No mention is made of the scales used.

One of the greatest advantages of air surveying, that of speed, has curiously enough proved to be one of its greatest handicaps. The survey may be completed so rapidly by air methods that payment might have to be made within, say, two years, instead of, say, six years, if done purely by ground methods. As the former may cost, say, a third of the latter, the fact that a larger amount of money is required within the two years period has prevented contracts being secured. This is an example of false economy, which unfortunately is very prevalent to-day, and is holding up development of benefit to the Empire and to trade.

Information Required for Estimating.—In order to prepare estimates for the making of an air survey, certain information is required, of which the following is the most important:—

(1) Size and position of area or areas to be surveyed.
(2) General description of the topography, supported by any available maps, sketches, or reports.
(3) If possible, the purpose for which the survey is to be made.
(4) Are obliques, verticals, or both required?
(5) Are they to be rectified?
(6) Are mosaics required? State whether to be rectified or not.
(7) Are maps required?
(8) Give scales for (4), (6) and (7).
(9) Does any type of control exist? If so give particulars.
(10) Is the ground control to be provided by the employers or the contractors?
(11) What sort of accuracy is required?
(12) Are contours required, and at what intervals?
(13) What facilities exist for the operation of aircraft and the housing of the expedition? Are these to be provided by the employers or the contractors?
(14) General particulars of the meteorological conditions in the area are essential, particularly in relation to conditions of cloud and mist.

It will be appreciated that so wide a subject as that implied by the title of this paper provides scope for many papers. As, however, it was on this subject that the lecturer has been invited to speak, he has tried to touch on the main points which are likely to be of interest to petroleum technologists, in the hope that others will supply the detail. The other section of the paper—Air Transport—in so far as it may concern the oil industry, will now be dealt with as shortly as possible.

Section II.—Transport

The use of aircraft for transporting personnel and material may be considered under three subsections:—

(*a*) Regular air services for the carriage of passengers, mails and freight operating to a time table.
(*b*) Other air services.
(*c*) Light aircraft.

Subsection (a), which mainly consists of subsidised trunk services, need not be dealt with here, as, apart from generally benefiting the community as a whole, they have no particular relation to oil-field development. The main trunk air routes of the Empire are being developed by Imperial Airways, Ltd., while both Australia and Canada have done a great deal in developing and subsidising regular air services within their Dominions. It may well pay oil companies to establish regular air services in their oil-fields, in order to link up with trunk services and with headquarters.

Subsection (b); Other Air Services.—It is submitted that by using aircraft in oil-field development, the oil industry should be able to effect many economies, both in administration and in actual work in the field. Although at present flying is still in the infant stages of its development, it may become of very great importance to the oil technologist.

Transport by aircraft of men and materials is of interest when saving of time is a main object, and it is understood that in many oil-field conditions or contingencies this is often the case.

It is suggested that there are also cases in which air transport provides the only means of conveyance, owing to natural or even political obstacles which prevent the utilisation of the customary methods.

Drilling machinery and casing in 20ft. lengths could be carried by aircraft to the site of a test well in territory surrounded by dense forest, difficult or swampy country, provided facilities can be made available for landing and taking-off of the aircraft.

It is understood that it frequently happens that some important and even vital piece of equipment breaks down, or is required urgently, to an extent that the life of a well may be threatened by its absence; it could be rushed to the spot by 'plane if the proper air service for such purposes was organised and available.

It is suggested that fires in the oil-fields could frequently be curtailed by the rapid conveyance of special fire-fighting equipment to the spot.

The rapid transport of material and equipment in cases of urgency has its parallel in the conveyance of executive officers, technical experts or specialists to places far distant from their base locations when need arises. Thus air transport is capable of enormously increasing the range of such people's usefulness in the case of an oil company operating over a large area.

In the medical services of the oil companies air transport is capable of playing a useful part, conveying medical officers or surgical equipment rapidly to districts where their presence is urgently required or rushing the patients themselves to hospitals for special treatment.

Subsection (c): *Light Aircraft.*—There are popular types of light aircraft available to-day which should be of the greatest value to the geologist, engineer or executive who is concerned with oil-field work. Being cheap to run and easy to handle, such aircraft could be used for travelling from one point to another for inspection purposes, for geological reconnaissance and even to a limited extent for photography.

The oil man who knows how to fly, or is prepared to learn, will find that he can carry a considerable load in a two-seater machine, while the maintenance of modern light aircraft is no more difficult than that of a private car. Greater attention to detail is of course essential, but it is very simple.

Operations.—It is understood that British oil companies are using aircraft to a limited extent, and that arrangements were made recently to use aircraft for transportation of personnel and supplies in connection with pipe-line construction.

Aircraft are used a great deal in the States in connection with oil-field development. An interesting example of their use comes from Mexico. According to *The Oil Trade,* of June, 1926, the transport of pay rolls by aircraft over territories infested by bandits was adopted by the oil companies operating in the country, and in four and a half years over 300 pay roll flights were made and about $25,000,000 carried over an aggregate of 320,000 miles.

A most interesting paper on "Air Transportation of Gold Dredges in New Guinea" was read by Mr. Charles A. Banks before the Institution of Mining and Metallurgy on July 29th, 1932. As the transportation of the heavy equipment described may have its parallel in oil-field development, the following facts extracted from Mr. Banks's paper are given:—

The problem involved the handling of a large volume of dredgeable gold-bearing gravel in New Guinea, situated at Bulolo, approximately 7 degrees South of the Equator at an elevation of about 2,250ft. No road existed to the coast, which was separated from the location by dense tropical jungle and a mountain range, the lowest pass of which was roughly 4,000ft. high. It was considered that the building of a road was not a feasible proposition, due to the heavy initial cost and maintenance in a tropical country with a heavy rainfall.

Two Standard tri-motored G-31 Junker planes, each of 1,575 h.p., were specially adapted to carry up to 7,000lb. of freight per machine—this weight being that of the upper tumbler shaft, the heaviest single unit of the equipment required to be transported. These two machines carried between them 2,500 short tons of equipment, in 1,000 trips from Lae on the coast, 50 miles to Bulolo, in the twelve months from April, 1931, to March, 1932. (See Fig. 8.)

In 1931 three Canadian mining companies, using their own aircraft to carry their prospectors with tools and supplies, carried a total of 530,000lb. of freight and 2,880 passengers a distance of 351,200 miles. This is apart from mining work carried out by operating companies offering aircraft for hire and charter.

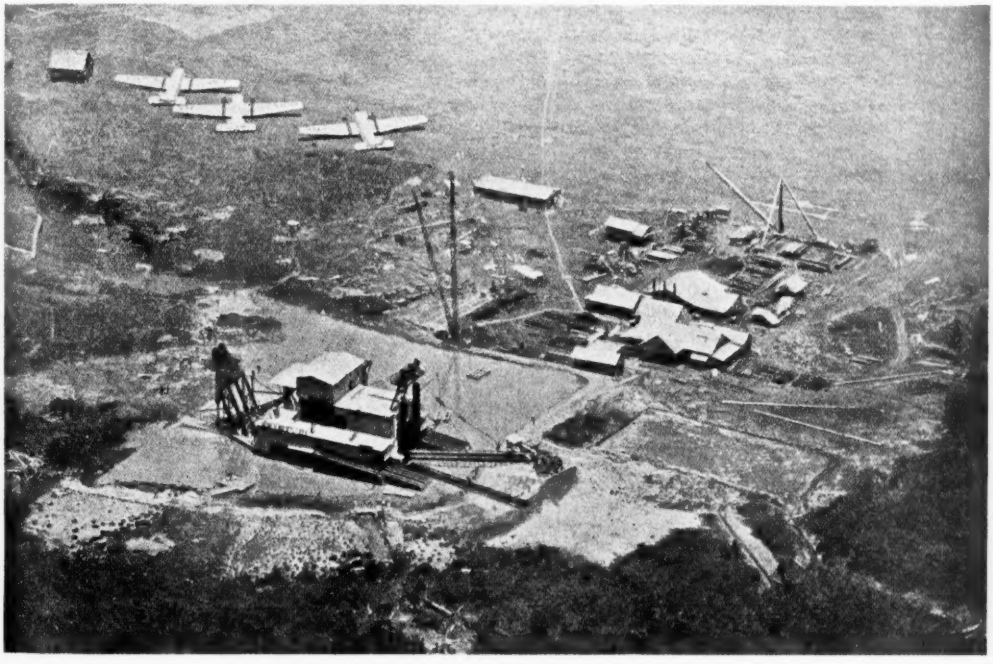

FIG. 8.

Aerial view of first completed dredge, showing also workshops, aeroplanes, and a portion of the Bulolo Aerodrome. All of this equipment was carried to the site by the aircraft seen in the background.

—Courtesy of Mr. C. B. Banks.

Cost.—According to Mr. Banks the cost of transporting the dredges, etc., in New Guinea, weighing 2,500 short tons, including the extra cost of sectionalising the equipment and field erection, came to $762,000, which at $3½ to the Australian pound is £217,715.

It was estimated that the total cost of building a road, including cost of haulage and road house accommodation, would total $1,200,000 (£342,857 Australian), as against the $762,000 (£217,715 Australian) for carriage by air.

Mr. Banks says that, although it is true that if a road was built they would have it for permanent use, he is satisfied that, under the conditions existing in

New Guinea, the aircraft will probably be more satisfactory as a permanent connection with the coast than will a road and will cost less to maintain.

The saving in money on interest at 5 per cent. on the tentative profit in sight of something over $20,000,000 (£5,714,286 Australian) was sufficient to pay the entire cost of the aeroplanes, and the landing of the whole equipment of four dredges and the power plant, from the ships' side to the site of erection at Bulolo.

An estimate for the operation of an economical air transport machine, of which the DH. Dragon is representative, is given as follows:—

The aeroplane, with two engines of 130 h.p. each and with maximum load of 4,200lb., has a maximum speed at sea level of 129 m.p.h. and a cruising speed of 107 m.p.h. Petrol consumption at cruising speed is 13 gals. per hr., oil 3 pints per hr. Maximum load, with 4½ hours range, consists of pilot, 6 passengers and 289lb. of baggage, or pilot and 1,350lb. of freight, with seats removed. Capacity of cabin when used for freight is 210 cu. ft. The following costs relate to operation in this country and are supplied by the De Havilland Aircraft Company, Ltd., who have a reputation for being conservative. The costs may be adjusted to suit special conditions. In order to secure the maximum reliability obtainable, not less than two aircraft should be estimated for:—

Capital Cost.

2 aeroplanes fitted for 6 passengers at £2,905	£5,810	
Incidentals, say	£581	
		£6,391

Annual Charges.

5 per cent. on capital	£319	
Obsolescence allowance at 20 per cent. ...	£1,278	
Insurance at 10 per cent.	£639	
Housing	£150	
2 pilots plus insurance at £600 each	£1,200	
		£3,586

Flying Costs.

Flying costs and maintenance, including mechanics' wages, are estimated by the makers at 35/- per flying hour. Assuming that the average ground speed is taken at 100 m.p.h., operating costs for 500 hours per year for each machine, making a total of 1,000 hrs. per year, work out as follows:—

Cost per flying hour.

1,000 hrs. at 100 m.p.h. = 100,000 miles per year

Total cost per flying hour = £3,586 plus (35/- × 1,000)

= £5,336/1,000 ... ... £5 6 8½

Cost per aircraft mile.

£5,336/100,000 = ... 12.80d.

Cost per passenger mile.

(6 seats) = ... 2.13d.

Cost per ton mile (1,350lb.) = ... 21.24d.

In considering operating costs of aircraft it should be remembered that a well run service on regular routes can average 1,000 flying hours per year per aircraft. A light aeroplane, costing from £600 to £750, can be operated at a sum not exceeding that of running a car of similar price for an annual mileage of 15,000 to 20,000.

Aerodromes and Landing Grounds.—For the operations already described in New Guinea, an aerodrome was made at Bulolo by clearing the jungle over an area of 4,000ft. by 1,500ft., of this area 3,000ft. by 1,500ft. was levelled for landing purposes. The work was costly, because heavy aircraft, weighing some 19,000lb. when fully loaded, were used, requiring good surfacing.

For oil-field work temporary landing grounds could be made, unless of course a regular service is to be established. In the first air survey made in Northern Rhodesia, before the special air survey aeroplane was built, 39 emergency landing grounds, each measuring 500 yds. by 100 yds., were made in the bush in addition to the main aerodrome, measuring 750 yds. by 750 yds. To-day, with the increased performance and reliability of modern aircraft, comparatively few landing grounds are required for emergency purposes. In the case of the first Rhodesian survey of 20,000 square miles of bush country, single engine aircraft were used, so that it was considered necessary to establish the 39 emergency landing grounds referred to. The survey of that area was completed without a single forced landing, so that it was decided to make an air reconnaissance over an unexplored area of difficult country where no landing grounds existed. As the flying party were anxious to do the job, permission was given, in view of the reliability experienced with the previous operation, but Providence objected to chances being taken, and one of the aeroplanes had a forced landing in a "dambo," fortunately without fatal results, and damaged its undercarriage. The crew had a very long walk through the bush to the nearest village, and the aeroplane had to be dismantled and carried to the nearest road by native bearers.

The survey of the 65,000 square miles successfully completed recently in Northern Rhodesia was made from four aerodromes and no forced landings had to be made. This alone justified the building of the Gloster A.S. 31 at a cost of over £15,000.

Under average conditions abroad aircraft carrying heavy loads for the purpose of oil-field maintenance and development could be operated off temporary landing grounds consisting of two cleared runways at right angles to each other, with one arm running in the direction of the prevailing wind. The dimensions of the arms being 750 to 1,000 yds. long and 100 yds. wide. From the end of the levelled run no object must appear above an imaginary line rising at an angle of 1 in 15 in the line of flight for a further 250 yds.

Freight and Handling.—The operations in New Guinea have proved that properly sectionalised freight can be handled in units weighing up to 7,000lb. perfectly safely with modern aircraft if intelligently handled and loaded. In 1925 the lecturer and others drew up a detailed proposal for carrying by air all the drilling machinery, power plant and casing necessary to bring a test well into production. A leading manufacturer of oil tools drew up detailed drawings for sectionalising the necessary equipment that would have to be carried. It was pointed out that in certain cases the great waste resulting from the abandonment of roads, which had to be built to get the material to the site, would pay for the cost of the aircraft and their operation many times over if the test well proved to be non-productive. Several months were spent in drawing up these proposals, but they were not taken up by the company to whom they were submitted.

At a later date the Air Ministry ordered a heavy freight carrier which it was claimed could be used for oil-field work. This order was placed as the result of the proposals referred to. It has been left to Mr. Banks and his colleagues to prove that the carrying of heavy materials for mining purposes was no dream of unpractical visionaries.

According to Mr. Banks, the Junker G-31 aeroplanes used had a cargo compartment 24ft. long, 77in. wide and 69in. high. The hatchway was 142in. in length by 60in. in width. The interior was free of obstructions with the exception of two sets of stays, placed approximately 12 and 18ft. from the front of the compartment.

The aeroplane to be loaded stood with its tail on platform scales, which were situated on a concrete loading apron on the aerodrome. A locomotive-type crane standing behind the wing, and to one side of the fuselage, lifted the freight into the cargo compartment, the correct loading being checked by the platform scales. Heavy pieces of machinery were fastened in position by light steel cables attached at intervals to the floor and also at the fore and aft ends. No trouble was experienced through cargo shifting.

To-day there is no difficulty in building or adapting aircraft to carry heavy oil-field equipment, while medium-sized aircraft of the 120 to 300 h.p. class could carry geologists with field equipment such as the Eötvös Torsion balance, and also "fishing tools" and other types of tools and equipment. Considerable experience is now available on the correct handling and loading of aircraft for heavy freight.

In conclusion, the lecturer wishes to record his great indebtedness to Mr. McConnell Sanders for having indicated the kind of information that Petroleum Technologists are likely to be interested in and for the considerable help that he has given with information and advice. The lecturer also wishes to include the name of Mr. Donald Gill in this appreciation for having kindly assisted with information and for permission to quote his paper and use his bibliography.

It was suggested that the following additions should be made to Mr. Gill's Bibliography:—

Aerial Survey in Relation to Economic Geology. By D. Gill, before the Institution of Mining and Metallurgy on November 17th, 1932.

The Manual of Map Reading, Photo Reading and Field Sketching, 1929, Issued by the War Office. Published by H.M. Stationery Office.

Handbook of Aeronautics, 1931. Published by Gale and Polden.

Air Survey. Lt. J. S. A. Salt, R.E. Paper before Royal Aeronautical Society, December 8th, 1932.

Méthodes d'Application de l'Avion et de la Photographie aux Recherches Géologiques. S. Zuber. International Congress of Mines, Metallurgy and Applied Geology, Liége, 1930.

Discussion

The President: The meeting would agree that it had listened to an extraordinarily interesting and instructive paper. The lecturer had stated in the paper that he had unfortunately to admit that he had to turn to the United States of America because he could not quote concrete examples of the success attained by British operating companies. From July, 1925 to April, 1926, however, the Sarawak Oilfields, Ltd., in Sarawak, had surveyed no less than 1,300 square miles, using aeroplanes of the Air Survey Company. They had carried out a large survey, taking continuous vertical and oblique photographs and drawing and mapping certain of the rivers to a scale of 1/10,000 and the whole of the area to a scale of 1/50,000. The company with which the President was associated owned at the present time no less than eighteen aeroplanes, operating in East Africa, South Africa, Australia, Egypt, Germany, Great Britain, America and the Argentine. The aircraft were used not only in the transport of personnel, enabling the general manager in a centre at, say, St. Louis to pay rapid visits to oil-fields some hundreds of miles distant, but also particularly in Africa and Australia, for survey work and the finding of suitable sites for aerodromes and so on.

Mr. Robert Annan (Consolidated Gold Fields, Ltd.): Being associated with companies which were using the aeroplane in connection with mining operations, he could give some details of the practical results obtained. On the subject of transport Mr. Hemming had already given full details of the methods employed by the Bulolo Gold Dredging Company in New Guinea up to the time when that company had transported the materials for one dredge and for the hydro-electric power plant into the field. This company had now completed and put into opera-

tion a second dredge; a third was under construction, and a fourth would be commenced as soon as the third was at work. The air transport system had worked with the utmost regularity, and construction had proceeded according to the original programme without delay. Under the existing conditions the speaker was sure that these results could not have been equalled by road transport, apart from the prohibitive cost of maintaining a road and transport equipment under tropical conditions and heavy loads. This undertaking had proved beyond doubt that, with careful planning and suitable equipment, heavy machinery could be transported by air with certainty and regularity, even under adverse climatic conditions.

He said that on the question of aerial survey he did not propose to refer to topographic work or to the reconnaissance of large areas, subjects on which others were far better qualified to speak, but would confine his remarks to aerial photography as an aid to detailed geological study. In the first place, it provided with great rapidity a plan on which observations could be recorded. Next, it gave a complete view of the area, which would guide the geologist where to go to look for information. This, in itself, might mean a great saving in time when compared with the laborious search for rock exposures on foot. Lastly, it brought into prominence structural features which might not be easy to recognise on the ground and which, in the ordinary way, might escape notice for a long time. It was the ability to take a wider view than was possible on the ground and to see a number of features in their proper relation to one another that made the difference. For instance, the slight surface depressions often caused by faulting or zones of shearing might not be very marked at any one point, but in the photographs their continuity and significance became apparent in a way that was unlikely to be the case to an observer on the ground.

For such work the vertical photograph and the stereoscope were essential, as only in this way did the features of relief become apparent. It was surprising how much information of this kind could be gained from photographs in circumstances which might be thought unpromising. It was, however, necessary to guard against seeing in the photographs more than was actually there. Any deductions made from them must be verified on the ground, and it was a safe principle that the clues might be found in the air, but the evidence must be provided on the ground. In short, the great value of aerial photography to the geologist lay in the rapid guidance it gave to the available evidence and in the assistance it gave in piecing it together.

Even in areas by no means new so far as mining operations were concerned, valuable information had been obtained regarding the continuity or repetition of ore deposits, and the function of aerial survey was by no means confined to the exploration of new areas. A good deal of work on these lines had recently been done in South Africa. New Consolidated Gold Fields, Ltd., had arranged with the Aircraft Operating Company, of Johannesburg, for a preliminary survey of the property of the Wanderer Consolidated Gold Mines, Ltd. The original survey had only covered an area of about six square miles, the cost of which, including enlargements of the contact prints, stereoscopes, etc., had been just under £200. The results of this survey had been so encouraging that a much larger area had then been photographed. The complete results of the later work were not yet available. Fig. 9 showed one end of that mining area, at which could be seen one of the old open pit workings. More of these old workings were visible, he said, at other points. Across the photograph there ran a definite line above which the vegetation was small and sparse, and below which it was much stronger and more conspicuous; this line represented the contact between a highly silicified ironstone and a sill of epidiorite. Under the stereoscope the line stood up as the crest of a ridge. The ironstone was repeated in another band at some distance; this other formation did not show on inspection of the print, but under the stereoscope it had the appearance of a kind of hog's back running

along the hillside, and was clearly distinguishable. The contact line could be followed to a point beyond which it was faulted; thereafter the track of the faulting and the curvature produced by its throw appeared in each area. The line could be followed right across the country, through a dark belt of trees to the corner of the map. The picture showed that the stream had a dog-leg course, and in the stereoscopic view it was possible to make out depressions running up the hill, accompanied by a little, but very marked, saddle-like depression in the crest of the ridge, where a zone of shearing passed through. The photographs had been taken from the height of 8,000 feet; the scale had originally been 1/9,600, but the pictures had been enlarged to double that size.

FIG. 9.

Air photograph of part of Wanderer Mine, described by Mr. Robert Annan.

—Courtesy of Wanderer Consolidated Gold Mines, Ltd.

Following on this, the Gold Fields management in South Africa had decided to have made an experimental survey of 20 square miles in the Far West Rand, in an area into which the extension of the main reef series had recently been traced by geophysical methods. In this area the main reef series was covered by a heavy layer of dolomite, and the object of the survey was to determine if lines of faulting could be traced. On this subject Dr. W. S. McCann had written to the speaker as follows: " The results of this test were most satisfactory, and we are being furnished with much valuable information, not only concerning faults, but the position of dykes along which chert has been developed in a manner hitherto unrealised."

The importance of this in planning future development was obvious. The speaker only regretted that he could not show any of these photographs that night; they were on their way to London by air mail. As a result of this test 300 square miles would now be surveyed at a cost of £5 10s. per square mile, including a complete set of stereoscopic photographs on a scale of 1/10,000 and a sketch map showing the results of the examination of the photographs.

A further survey of 15 square miles, covering the area of the Sub Nigel Mine, was also being made, the cost for this smaller area working out at £21 per square mile. All this work was being executed by the Aircraft Operating Company of Johannesburg.

He realised that the foregoing had little direct bearing on the geology of oil deposits, but hoped that it might be of interest that mining companies were finding aerial survey of great value, not only in the prospecting of new countries, but also in the solution of structural problems in well-established mining districts.

Major B. DAY: He proposed to tell the meeting a little of his own experience in the new Canadian mining area known as the Great Bear Lake Field, which should be of particular interest to oil technologists at the present time, because it was almost entirely dependent for its future upon the oil industry. The nearby wells at Fort Norman, probably the world's most northerly commercial oil-field, were situated on the same parallel of latitude as the new mining discovery.

The speaker showed a map of the North-West Territories. Traversing the centre of the Great Bear Lake, he said, was the great geological division known as the Canadian Shield. On the east side the formation was pre-Cambrian, on the west it consisted of Palæozoic sedimentaries. On a particular point on the west shore of Great Bear Lake, known as Scented Grass Hills, there was a very large lignite coal deposit, which seemed to be about 15 feet in thickness. In another part of the area were situated the oil wells developed by the Imperial Oil Company of Canada, which had been capped in 1921 and had lain dormant until 1932, when they had been opened up again. A small still had been put in and gasoline sufficiently good for the new companies' compressors and the ordinary mining machinery, together with crude oil for Diesel engines, had been made available. At the present time the rates were rather high; the Imperial Oil Company charged 20 cents for an imperial gallon of crude oil and 90 cents for an imperial gallon of gasoline. So far they had not been able to turn out a product of sufficiently high grade for aeroplane work.

The area was rather a long distance from so-called civilisation. The nearest railroad, 800 miles to the south, ended at Fort McMurray, some 300 miles north of Edmonton. In the old days the only way of access to Great Bear Lake had been a water route: Athabaska River to Lake Athabaska, the Slave River to the Great Slave Lake, and Mackenzie River to Aklavik, with a branch route at Fort Norman to the Great Bear Lake via the Bear River. In the pioneer days the air route had followed the water route. One of the men, however, had decided to take a chance by flying directly south to Fort Rae, on Great Slave Lake, and down to Fort McMurray by the short route. On the way out he had noticed some peculiar deposits and had gone back to look at them; in this way the new radium and silver finds had been discovered.

The work that the speaker's company was doing was still in the preliminary stages. He had fortunately had a little experience in the oil end of the aerial survey business in California some years before, in the Button Willow and Kettleman Hills fields of the San Joaquin Valley, and had found that at 10,000 feet it was possible to detect outlines of the sedimentary deposits, and to see dome formations and anticlines which could not be distinguished on the ground. It had subsequently become his fate to journey to this northern district, where he had decided to obtain the interest of the other mining companies in order to have an aerial map made of the area which would assist them in their exploration work. This mapping had been very necessary because the ground was very

rugged and the expense of taking men, provisions and equipment into the areas to be prospected was considerable. It had become of vital necessity to limit ground prospecting activities to those areas where there had been at least a good chance of a profitable outcome. Four of the companies had combined and guaranteed $2,500 to the Canadian Airways, Limited, to make a survey of the area round Echo Bay. This area was roughly 15 square miles in extent and, as the meeting could see from the large map in the library, to which Mr. Hemming had referred, they had made a very good job of it. Unfortunately, through one delay and another—first, adjusting the camera, and afterwards bad weather—they had been unable to get the proofs to the companies last season in time to be of very much use on the ground. The speaker's enterprise had therefore proceeded with its individual air reconnaissance work, which it had subsequently checked by the aerial photographs.

The speaker said that he was entirely in agreement with Mr. Annan on the real value of aerial survey. Its chief value was from the point of view of reconnaissance, by cutting out a lot of doubtful ground and limiting activities to ground which showed the greatest possibilities. The actual work had still to be done on the ground, but in the reconnaissance made last summer the surveyors had examined five groups of properties, covering some 5,000 acres in all, making two trips over each one at a height first at about 5,000 feet, and then at roughly 1,500 feet. This had been done in four flights, each of one to two hours. In these four flights the workers had located 14 shear zones as likely prospects, and of these zones nine had been found to be well mineralised. The surveyors had been somewhat led astray at first by going for quartz, which, of course, showed up much more clearly, but in that area the quartz was not a good leader for the kind of mineralisation for which they had been looking. In the course of a month the speaker and an assistant had covered several thousand miles, and had been enabled to plot three new areas for the prospecting crews to work on during the next season. In those latitudes there were three and a half to four months of open season in which there was no snow or serious interference from the weather and work could be done; this survey would have taken three or four summer seasons for prospectors to cover that ground and gather much less accurate preliminary information than the airmen were able to provide. The air survey had therefore probably expedited the work by about two years under the climatic conditions of the far north.

The aerial mapping expedition had flown from Fort McMurray to Echo Bay; had stayed there 12 days all told to get their pictures on account of bad weather, and had returned to Edmonton; they had sent the pictures from Edmonton to Montreal for photographic development work, fitting of the mosaic, etc. The total cost had been approximately $3,500, or about £47 per square mile. The time of the actual photographic work had occupied seven hours.

Mr. Hemming had mentioned the transportation record which had been set up in 1931 by the three Canadian mining exploration companies, who had carried some 250 tons of supplies and nearly 3,000 passengers over a distance of 350,000 miles. Much of this flying had been done in the North-Western Territories and a little south-east of it. In 1930 and 1931—mostly in the latter year—commercial transport companies operating in the area, on the Aklavik run and Great Bear Lake run, had carried mail, freight and passengers, had taken sick and injured men and women to hospital, had assisted the Canadian North-Western Mounted Police, and had flown some 600,000 miles without even a forced landing.

Speaking of the costs of transportation, the speaker said that it was difficult to use the present cost as a basis. At the present time this area was a luxury product. It had been recently established as a mining centre, and since the ore recovered was of extraordinarily high value and could be high graded and brought out as a cobbed product at a profit, the interests were suffering very largely from heavy charges by the aviation companies. However, three of the mining com-

panies had put in their own planes and others were doing the same, and the cost would probably soon fall very materially. In the present year his company had been able to ship ore from the Great Bear Lake to Fort McMurray, 828 odd miles by plane, on empty return journeys, at $7\frac{1}{2}$ cents per pound; considering that these planes carried about 1,000 pounds of pay load, the cost would work out at about 9d. per flying mile.

The speaker then showed a number of lantern slides of air photographs taken in the North-West Territories, including Figs. 3 and 4. Fig. 3 illustrated a fault over which he had flown for 25 minutes at about 100 miles an hour—a distance of about 35 miles. Fig. 4 showed a large quartz outcrop on which some copper had been worked in the early days of the present excitement and which had attracted the first pioneers into that district.

Mr. R. Bourne (Imperial Forestry Institute, Oxford): All his experience of interpreting air photographs, both on and off the ground, led to the same conclusion: that it was essential to approach the question from a regional standpoint. Every countryside was divisible into a series of regions, the larger of which were generally recognised; but if this regional division was carried to its logical conclusion, the country could be divided into relatively small units, the size varying with the general character of the countryside. When the surveyor compared a photograph in one region with the ground and examined it in detail, studying everything that it showed, and then studied another photograph of the same region, he would find that he worked much faster. The second photograph would contain much that he could interpret straight away without having to verify it on the ground. On a third photograph of the same region he would work faster still. If he took another photograph, a part of which covered the same region and a part extended into another region, immediately he came to the boundary on the ground he would find that he had to begin learning again. He would encounter certain features which he might be able to interpret straight off without inspection of the ground, but in some cases the photograph would be quite unfamiliar to him. He would then proceed to interpret selected photographs of the new region, and from what they taught him he could again accelerate his work.

In general, he would choose some suitable orientation for his sampling work, and proceed to work across country. Suppose, for instance, he had a shrewd idea of the physiography and geological structure of the countryside and could say that lines from north to south would be the most desirable for the purpose of sampling; if he interpreted photographs taken in that direction and studied the regions, he might be able to take other photographs of the regions sampled, and, provided he recognised each region, he should be able to interpret the photographs without going to the ground. If, however, he failed to recognise the region with which he was dealing, his interpretation might be wrong. Thus, in his opinion, the essential point in the interpretation of all photographs, unless everything was being checked on the ground, was to recognise the actual region with which the surveyor was dealing.

Wing Commander F. C. V. Laws, O.B.E., R.A.F. (Commandant of the School of Aerial Photography): The cameras in use at the end of the war had been those developed during that period, and had not been designed purely for survey work, but to give pictures of a military nature in the various theatres of war. The development since 1919 had been entirely on the lines of cameras for air survey, with all the equipment necessary for the rapid production of photographs accurately taken and recording all the various data required for that purpose. Such apparatus had reduced the work of the observer and of the pilot to a minimum. Those companies who were now equipped with cameras made in this country could feel a certain amount of natural satisfaction and know that they would get suitable results without fear of frequent breakdown. The speaker

concluded by saying that he had been most interested to hear the present commercial uses of air photography.

Flight Lieutenant CAMPBELL: In 1928 two Seagull amphibians of the Royal Australian Air Force had made a trial flight round New Guinea and over the mandated territory with the geologist, Nason-Jones. Sketch maps had been made of features of geological interest, supplemented by oblique photographs taken on definite lines of bearing. The speaker had unfortunately not been able to get a copy of the report during the last two days, but from what he remembered the main results had been to show definitely that certain areas were quite out of the question from the point of view of oil-bearing possibilities. The positive information had not been very great, because on account of the very heavily timbered tropical country the actual features of the ground had been very difficult to distinguish, but the work had certainly given a great deal of very useful negative information. Again, last year extensive prospecting had been carried out by two Air Force Wapiti machines, in collaboration with Mr. Woolnough, the Commonwealth geologist of Australia. They had flown about 15,000 miles and taken about 3,000 photographs, mostly obliques, of Central Australia, Queensland, the Northern Territory and the islands off the Northern Territory, including Melville Island and the north-west coast of Western Australia. So far no report had been issued, but it had been completed within the last month or two and should be forthcoming very soon.

Dr. A. WADE: Four papers in quick succession, each dealing with a different aspect of the use of aircraft in field work, seemed to indicate growth of interest in the subject. Mr. Hemming's contribution from inside knowledge was particularly useful. But he felt that the manner in which aeroplanes could, perhaps, be of most use to geologists had not yet been dealt with, and that was the use of aircraft for rapid visual reconnaissance as apart from photographic surveying. Such methods were not only more economical, and therefore more likely to be used by the smaller concerns, but would give the airman a much wider field of work, especially in areas which had already been more or less surveyed and mapped. Some of the data utilised in his recent paper on the Ionian Archipelago had been acquired in this manner.

After all, the use of aircraft in surveying was merely the development of a method used by all field geologists. They had always climbed mountains, or even trees, in order to increase their range of vision and to attempt to get geological pictures over as wide an area as possible. They had planned their work and their routes on the basis of information so gathered, often saving much time thereby. The aeroplane had given them the opportunity of attaining still greater heights and, in consequence, still wider vision, as well as mobility and increased speed of working. There was no doubt as to its utility and economy in certain conditions. But it was easy to make mistakes. They could not always be sure of formation boundaries as seen from the air, and even marked changes in the distribution of vegetation were sometimes to be regarded with suspicion by the geologist—both of which observations only meant that surveying from the air could never do away with the necessity for the man on the ground. In any case, fossils had to be collected as well as hammer and spade work for the examination of changes in lithology, perhaps in minute detail.

It was, however, true to say that the eye of the aeroplane camera sometimes saw more than did that of the observer on the ground. In 1924 photographs were taken from the air of a series of ridges in Central Queensland at the instance of the Government geologist, Mr. Dunstan. Structural features, which had been puzzling to geologists, were quite simply explained when the photographs were examined. A good deal of investigation from the air had been done in Australia, especially in connection with the search for oil. In no country were conditions more favourable to reconnaissance by aircraft. The work of drilling for oil had been going on in the Kimberley region in the north-west of Western Australia

for some years. In 1924 it took 14 days to reach that area from Perth. It could now be done in one day. At the time of his visit a very sick man was picked up and taken to hospital within 24 hours, a feat which had made a deep impression on the public.

In densely forested country, as in New Guinea, the use of the aeroplane to the geologist had its limits. In the first place, the cost of preparing bases would be prohibitive for any but a successful enterprise. Secondly, although a photographic survey could provide rapidly a general topographic picture, showing hills, swamps and the main drainage system, his experience indicated that the pattern made by the smaller streams came out very imperfectly, if at all, such streams being hidden by the density of the foliage. Unfortunately, the geologist depended upon these streams for the great bulk of his information.

The use of the contouring stereoscope seemed to have its limits at present also. He was informed that errors could be serious unless a very efficient check was kept on the ground. This was a matter of some importance to the geologist who was elucidating structure.

Dr. Wade said in conclusion that he would like to refer to one important omission from Mr. Gill's bibliography. This was Dr. Stanislaw Zuber's "Methodes d'application de l'Avion et de la Photographie aux Recherches Geologiques," presented at the International Congress of Mines, Metallurgy and Applied Geology at Liege in 1930, which did, to some extent, deal with visual reconnaissance, and supplied data which might be important in that connection.

Mr. T. R. H. Garrett: It was almost impossible for those geologists who had not themselves made use of the aeroplane to realise what an asset it is. But he wished to stress Mr. Annan's remarks that the geological work from the air must always be followed by work on the ground.

As an example, two years ago, in the Far East, he agreed from an oblique (not vertical) inspection with the structure previously determined from an oblique reconnaissance; but, when he came to work on the ground he found that the structure was quite other than that which he had supposed.

Mr. C. A. P. Southwell: He spoke as one who had had experience in the use of the aeroplane by the petroleum technologist.

As far as the speaker's company was concerned, an aeroplane was of great help to the senior staff for transport purposes, and to the geologist, and road and pipe-line engineers for technical work. His experience was that every available opportunity was taken by the staff to see things from the air which enabled the personnel concerned to obtain a quicker, better and broader picture than could possibly be obtained without very lengthy examination on the ground.

Unless one had experienced it, one could not appreciate, for example, what a splendid examination of a surface-laid pipe-line one could make when flying along it at 300 feet above the ground.

With regard to the geological side, the view of the geology obtained from the air gave one a broader and clearer picture, and would in the future provide wonderful opportunities for geological instruction.

He could not agree with the last speaker that the results obtained, either with the eye or photographically from the air, would provide a picture very different from that resulting from actual geological survey on the ground, certainly not as far as vegetation-free countries were concerned.

His experience had been that following surface mapping the geology in barren countries could be checked from the air, and minor errors made during the surface mapping could be corrected. He had seen an instance where a structure had been missed by geologists on the ground, whose traverses had passed on either side of it, but which was subsequently observed by an aerial reconnaissance, which instanced how valuable the aerial examination could be.

Apart from actually photographing the country, the aeroplane was of great value in going over the area quickly so that the geologists could see in which

areas detailed surface work would be of value, and by this means they could avoid the delay and expense of mapping stretches of country of little interest from a geological point of view.

He had had the opportunity of examining some of the photographic maps of the Orinoco Delta, which the speaker had mentioned in his paper, and had a limited experience of flying in Trinidad. The photographs which he had seen of the delta area provided very interesting evidence of mud volcanoes and gas-oil seepages, indicating probable fault lines or junctions of formations. As one who had had the experience of an aerial view of tropical forest, in addition to that of barren rocky countries, he wished to point out the difficulties of interpretation, both from a geological and engineering standpoint, of photographs taken in a tropical country covered with a blanket of thick vegetation, when compared with photographs of uncovered rocks in such countries as Persia, where interpretation was comparatively simple. In all cases, assuming sufficient preliminary ground examination had been carried out.

From an engineering point of view the aeroplane was invaluable in preliminary surveys for test wells, where road-making was likely to be both difficult and expensive, as it reduced the time which the engineer would require, by indicating the most likely points for investigation and survey.

He was interested in Mr. Hemming's remarks on transportation of drilling material. Whilst many companies had had experience of transporting small items of equipment, such as fishing tools, landing nipples or special well instruments, he was not aware that any oil company had actually transported the whole of the equipment required for a test well by means of an aeroplane. The modern test well, with its camp, comprised some 1,500 tons of material, and as far as the speaker's experience was concerned the smallest weight to which the heaviest part of the plant using internal combustion engines could be broken down and packed for transport was in the neighbourhood of 6 to 7 tons. Mr. Hemming had quoted figures of $3\frac{1}{2}$ tons, and he was interested to know if any details of the plant transported by aeroplane were available. As far as the 6-7 ton figure was concerned, he assumed it could be dealt with by increasing the size and power of the aeroplane; it might, however, mean larger landing grounds.

He was very interested to hear that heavy metal-mining equipment had actually been transported by aeroplane in order to avoid expensive road making. As far as test drilling was concerned, when comparing the cost of air transport with road making, they would have to include the cost of removing from the site of the test well the greater part of the equipment in the event of the well proving to be a failure. In the event of the well proving commercial oil, then road making would be necessary, and he felt that the question of transporting equipment for oil development was not quite comparable with metal mining.

In gold mining the gold won could be transported from an inaccessible mine by means of the aeroplane, an entirely different picture from oil development, but no doubt we should see great and rapid progress in the use of air transport in the petroleum industry, as it had already proved of the greatest value to so many of the technical arms.

Mr. T. DEWHURST: He hesitated to express his views after Major Garrett's remarks, as he was definitely of opinion that visual aeroplane reconnaissance was of very great value in geological exploration, provided that the geologist engaged in the work was experienced in flying, was familiar with the appearance of the strata and had a good working hypothesis of the general geology of the region under observation. At the present time visual observation was more valuable than aeroplane photography, as the latter required closer checking, but doubtless as time went on photographic mosaics would become increasingly useful.

The speaker agreed that the main sphere of aeroplane observation and photography was in reconnaissance. At the present time it did not promise to be so helpful in oil-field development. Nevertheless, he had had in his charge

for some years a photographic mosaic of the Yenangyaung Oilfield, which showed very clearly the general geological structure of that field, and he appreciated that such a photographic mosaic might be very useful during the early stages of the development of an oil-field.

Mr. D. A. SUTHERLAND: He desired to confirm what Mr. Dewhurst had said as to the value of visual observation in addition to records by photographs. The study and interpretation of aerial photographs, like the taking of them, required a great deal of hard work and patience, and was a special subject in itself. He had taken photographs somewhere about thirty years ago, at a height of 1,500 feet, over Los Angeles in California from a balloon. There was a reproduction in the *Petroleum Review* in 1902, and a glance would show the great alteration in the country that had taken place since then. Subsequent to the war he had had several opportunities of appreciating the advances made by aerial surveys. During the last three or four years the speaker had made several expeditions into the very difficult country surrounding the southern part of the Dead Sea, in Palestine and Trans-Jordan; he had travelled by boat, on camels, on horses, as well as on foot, but owing to the mountainous nature of the terrain, with deep gorges and high precipitous hills, he had found it very hard to form an opinion quickly as to the character of anticlines or the presence of faults. Last September, however, by a fortunate chance, he had been flown in a Puss Moth aeroplane on a perfect day, when the whole district could be seen most plainly, and he had been able to trace the anticlines running for miles. The magnetic compass in front of the pilot enabled him simultaneously to make observations and take directions of geological structure or other features of interest, such as means of access. The result was confirmation or modification of views held or formation of entirely fresh ideas to be followed up on the ground. In three hours he had covered over 800 square miles and memorised the details as a comprehensive whole. He carried a visual photograph in his mind which he could reproduce clearly in memory, although he did not possess a photograph.

The PRESIDENT: He was quite convinced that the aeroplane was a great aid to the study of the physiography, if not the geology, of a country. One of the most enjoyable flights he had ever had had been from San Francisco to Los Angeles. The view, owing to the lack of vegetation, was wonderful and gave a clear picture of the river systems. He proposed a hearty vote of thanks to the lecturer and to the various colleagues who had helped him in preparing his fine lecture and exhibition. The only regret of the meeting would be that it had not sufficient time to study all the details which were on view in the library. The vote of thanks was carried with acclamation.

The following written contributions to the discussion were received subsequently:—

From Mr. C. T. BERRY: In his flying experiences he had been much impressed with the ease with which geological features can be picked out, and could definitely state that the aeroplane should be part of the equipment of any modern oil company. With it, and the modern aerial camera with its super long-distance lens, a geologist can cover hundreds of square miles over any given area in a day, pick out by eyesight quite easily any likely looking structures, and with an aerial photograph of the same structure trace its peculiarities, which is of infinite value to the geologist when making a close-up inspection on foot, whether the structures are exposed, semi-exposed, or fully covered with jungle. In the case of wooded or jungle areas, the trained eye of the experienced geologist can pick out structures by the form of flanks, dips, etc., and get a more general bird's-eye view, which is impracticable on foot. Quite true, these spots must subsequently be closely inspected on foot. The argument put up that that which looked like a structure from the air turned out to be nothing, proves that from the air one is less likely to miss something that is a structure, with its usual outstanding information known to oil-field geologists in general. The geologist should have

several preliminary hours' experience in the air to acquire what he termed "aerial vision," before attempting to fly over and take aerial photographs, or survey any given area. Aerial photographs and surveys cannot be taken in foggy or misty weather, but with the development of infra-red-ray photography this may become possible. The footslogger, also, has to hold up on these occasions when investigating new territory, it being a simple matter to pass a possible structure in the mist. The geologist may fly at any altitude to suit his own style, and he can inspect a given area in four hours, in any aeroplane, that would on foot take six months, and in comfort and with much less expense. The aeroplane has also come to stay in the transport of oil-field equipment. The modern drilling rig can be taken by commercial aeroplane, the largest piece would weigh about 1½ tons, taking it for granted that the drilling motive power is motors. He knew from actual experience that an aeroplane can land within a very few miles of any oil-well site that he had seen. These commercial aeroplanes can be built by several aircraft manufacturers in England. The ordinary modern Gipsy Moth aeroplane can pick up about 800lb. freight or load, and deliver it hundreds of miles over any class of country in a very few hours. It is much cheaper to clear an aerodrome site than to cut and maintain a road for heavy transport through rugged and difficult country. Think what a saving of time and money this would mean when work is shut down waiting on some special fishing tool, a hospital case, or people cut off by floods or otherwise isolated. He had been in these positions, and spoke from personal and practical experience.

From Mr. L. OWEN: He would like to congratulate the author on the reserve with which he has put forward the claims of aircraft and would thank him for indicating so clearly the limitations which are, at present, inherent to its use.

The importance of air photographs for the geologist cannot be over-emphasised, even in heavily wooded country. Heavy bush, so common in tropical areas, masks the ground from the air, of course, but the difficulties of the ground worker in forest land are so great, normally, that even the little additional information that may be gleaned from an air photograph of such areas is very welcome.

The interpretation of such photographs, however, should never be attempted without first obtaining a thorough ground knowledge *within* the area covered by the photograph. Otherwise, serious error is almost inevitable.

Plant ecology has long been usefully employed by the geologist, but it should be emphasised that a change in vegetation does not *necessarily* imply a change in the underlying geology, nor is a change in the underlying strata invariably accompanied by a change in vegetation.

In heavily timbered land, also, particularly in the tropics, topography is sometimes developed plagioclinally to the main structural trend.

To his mind, one of the chief dangers of the extended use of air photographs by the geologist is the tendency to pass over, without due examination, such areas as appear to be devoid of geological information. In this connection, it may be noted that small streams rarely show up in a small-scale photograph of heavy forest land.

The more experienced worker will, of course, be wary, as he will recall his own discoveries of vitally important data in the most unpromising environments, but the young man in a hurry may easily be misled.

REPLY TO DISCUSSION

He felt that he had been fully justified in turning to the United States of America to quote examples of the use of air survey for oil-field development, because it had resulted in the President and other speakers referring to actual work carried out for the British oil industry. In spite of what the President and other speakers had said, he felt bound to reaffirm, with all due respect, that, in comparison with the work which had been done in the United States, little had been done for the British oil industry.

The lecturer felt greatly encouraged, however, because it was clear from the remarks made by those who had contributed to the discussion, that the potential value of aircraft and the air camera for oil-field development was now appreciated by petroleum technologists.

He thanked Mr. Annan for the additional information regarding the further development which had taken place in connection with the Bulolo Gold Field Transport Service. He felt that the continued success of these interesting operations should establish definitely the aeroplane as an efficient carrier of heavy mining equipment in undeveloped countries. He hoped that the British aircraft constructors would give some attention to this matter, and that those companies which supplied the oil industry with tools and drilling equipment would consider designing equipment for transport by air. The lecturer thought that Mr. Annan was the first mining expert to stress the value of air photographs in providing additional information in areas already carefully geologised on the ground. This opened up further possibilities for air survey work in developed areas.

The figure quoted of 3½ tons, which Mr. Southwell referred to, was concerned with the dredging equipment used in the Bulolo operations. The lecturer thought that Mr. Southwell would be able to get all the information he required on this subject from the paper by Mr. Banks. Mr. Banks points out in his paper the desirability of using low-wing monoplane types, because of their adaptability for the loading of heavy equipment, and the lecturer hoped that British aircraft constructors would note this point. It seemed unfortunate that all of the transport work referred to in the paper had been carried out by foreign makes of aircraft. He hoped that aircraft constructors and the tool manufacturers would now get together with a view to seeing what could be done, and, if the lecturer could help in this direction, he would be very pleased to do so.

The dredging equipment for the Bulolo operations was specially broken down in sizes suitable for transport by air, and, no doubt, the oil well supply companies could break down the equipment necessary for drilling test wells for carriage by aircraft. The lecturer understood that the heaviest unit would be the motor, and that could be broken down into parts, the heaviest of which should not exceed 3,500lb.

As regards the point raised by Mr. Southwell of the necessity of building a road, should a test well bring in commercial oil after it had been drilled by machinery brought to the site by air, the lecturer understood that there had been cases where roads had been built, at considerable cost, to the site of a test well only to be abandoned at great loss, when, after drilling, the test well proved useless. The lecturer suggested that there might be cases where such wastage could be avoided, if aircraft were used in the early stages of drilling the test well. Then there would be no need to incur the expense of road building until the test well proved worth the cost.

In referring to Major Day's remarks, the lecturer said that he was glad that Major Day had recorded that the new radium and silver finds in the North-West Territories of Canada were due to their being seen in the first instance from an aeroplane; but, of course, when first seen, they appeared as some peculiar deposits and had to be prospected on the ground.

The lecturer wished to stress that it was not claimed that air photography and air reconnaissance could offer anything more than a clue, as Mr. Annan had said. He hoped he had made this clear in his paper and he was glad that other speakers also had emphasised this point.

The lecturer was glad that Mr. Bourne had laid down the policy to follow in interpreting air photographs. Mr. Bourne was an authority on this subject and had struck the right note of warning. Unfortunately, air surveying, being new and rather spectacular, had suffered in the past through the exaggerated claims made on its behalf by uninformed enthusiasts. This had undoubtedly caused many professional mining men and engineers to look upon air surveying

with some mistrust. However, it seemed clear, from the attitude taken by those who had contributed to the discussion, that the subject was now being looked upon by members of the Institution in a serious light, and he felt that this augured well for the future.

Dr. Wade and other speakers had struck the right note, and so long as aircraft and air photography and reconnaissance were looked upon as an aid to the geologist, the engineer and the surveyor, and not as a means of replacing these essential experts, he felt that matters should now progress to the mutual benefit of the oil industry and of commercial aviation.

The lecturer was pleased that Flight Lieut. Campbell had referred to the work that had been done in Australia, and hoped that some reports would be available on this subject soon. He had tried to get some information to include in his paper, but, unfortunately, the information had not yet arrived.

Dr. Wade, Mr. Dewhurst and Mr. Sutherland had suggested that aircraft could be of greater use to geologists for reconnaissance than for photographic surveying. The lecturer suggested that a combination of the two methods was really what was required. If a careful reconnaissance had to be made of a large area, quite a lot of valuable photography could be carried out while on the flight at little extra cost, especially when compared with the value of the information which might be secured. The lecturer wished to thank Dr. Wade for suggesting an addition to Mr. Gill's bibliography, and hoped that other members of the Institution would be able to suggest additions which should be included.

With regard to the written contributions to the paper, he was glad that Mr. Berry was such an enthusiastic supporter of the use of aircraft in connection with geological prospecting, but wished to stress that in order to obtain the best results, air surveying must be treated as a precise operation, requiring close co-ordination between all those concerned with the work. Mr. Berry says that the ordinary modern Gipsy Moth aeroplane could pick up about 800lb. freight or load, and deliver it hundreds of miles away over any class of country in a very few hours. The lecturer would point out that, when filled up with fuel for a range of 290 miles, and after allowing for the weight of the pilot, the available load for freight on a Gipsy Moth is 475lb., and not 800lb., as stated by Mr. Berry.

Mr. Owen states that in tropical countries the heavy bush masks the ground from the air, but even the little additional information that may be gleaned from an aircraft in such areas is very welcome. The lecturer understood that, even in heavily forested countries, where the forest canopy closed over the streams, the course of such streams could be traced in many cases by the difference in the density of growth near the water.

It was also understood that abandoned native workings could be located in certain instances from air photographs, in view of the fact that, when a clearing has once been made in the forest, the second or following growths are much thicker than the first growth, and consequently a difference is seen in the forest canopy as shown on the air photographs.

Mr. Owen raised an important point in stating that air photographs may cause the geologist to pass over certain areas without due examination. The lecturer suggested that this was far more likely to occur should the geologist only rely on visual reconnaissance. If visual reconnaissance is used and is supported by air photography, it would seem that Mr. Owen's objection should be overcome to a large extent.

The lecturer wished to record his appreciation of the valuable remarks and suggestions that the various speakers had contributed to the discussion.

He was much indebted to Mr. Robert Annan for describing the use of air survey methods in connection with mining work in South Africa, and for kindly lending photographs and a stereoscope for the benefit of those interested.

The lecturer also wished to thank Major Bernard Day for contributing remarks on air survey work in connection with the opening up of the North-West

Territories in Canada. Major Day had also kindly lent a stereoscope and stereo photographs for exhibition purposes as well as a most interesting mosaic of part of the Great Bear Lake district.

In conclusion, Mr. Hemming said that it gave him the greatest pleasure again to record his thanks to Mr. McConnell Sanders, a member of the Council, for the great help that he had given in connection with the preparation of the paper, and to Mr. Donald Gill for so kindly allowing him to make use of his paper. He apologised to Mr. Banks for so freely using his paper without his permission, but as Mr. Banks was abroad it was not possible to ask him in time. The lecturer also recorded his appreciation of the assistance that the following had given him:—

Smith's Aircraft Instruments for having gone to considerable trouble in fixing up the Pilot's Assister and also the Holmes telecompass which were shown in working order in the library; the Williamson Manufacturing Co., for having sent a working model of the camera and for the loan of certain slides; Messrs. Barr and Stroud, Ltd., for the loan of their topographical stereoscope; Messrs. W. F. Stanley and Co., for having lent four pairs of stereo spectacles for the examination of air photographs; Capt. C. E. Ward for lending a photograph. Lastly, the lecturer wished to thank the Aircraft Operating Co., Ltd., the Air Survey Co., Ltd., and Aerofilms, Ltd., for the loan of certain slides and for supplying certain photographs and information.

In concluding his remarks the lecturer said that he hoped that what he had said would be taken as being quite impartial, as he was not associated with any company. He was genuinely inspired by a wish to see the wonderful services, which he knew that aircraft and the air camera could render to Empire and trade development, made full use of, particularly by the British oil industry.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Regular abstracts of Patent Specifications received by the Society will be published in future in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aerodynamics, Stability and Controllability

393,074. *Improvements in or Relating to Aeroplanes or the Like.* Nazir, F. P., Ava Mansion, 795, Dadar Colony, Dadar, Bombay, India. May 17th, 1932. No. 13,999.

Method of providing a means whereby the wings of an aeroplane may be prevented from stalling and by which the stability and controllability may be improved. Anti-spinning qualities and increased lift are also referred to.

The wing is provided with an auxiliary plane of thin section, and preferably of a somewhat elongated rectangular shape which normally rests closely on the top of the wing, somewhat forward of the centre of the chord, and with its leading edge some distance to the rear of the leading edge of the wing. Means are provided for enabling this auxiliary plane to be raised a short distance from the wing, either positively or automatically when the stalling angle is reached, so as to leave a gap between it and the wing. An air passage may also be provided through the nose of the wing elongated in the direction of the span. A claim is also made for a folding device for aeroplane wings in which the wing has a central spar, on which, after unlocking, the wing can be rotated into a vertical plane and folded back parallel with the side of the fuselage.

393,436. *Improvements in and Relating to Automatic Steering Gear.* The British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. (Assignees of Becker, H. I., 1036, Garner Avenue, Schenectady, County of Schenectady, U.S.A.) Convention date (U.S.A.), Aug. 12th, 1931.

A system by means of which the course flown by the aircraft with reference to a stationary point, such as the destinations of the craft, is predetermined by

adjustment of equipment on the craft itself, as by means of a radio beacon. This radio beacon may comprise any convenient broadcasting station which may be located in proximity to the destination of the aircraft. A further object is to provide means by which the directivity of a radio receiver may be controlled in accordance with the direction of the earth's magnetic field.

393,687. *Stabilising and Safety Device for Aircraft.* Oehmichen, 16, Rue de Villiers, Valentigney (Doubs), France. Convention date (Belgium), Jan. 17th, 1931.

A scheme whereby a balloon rigidly fixed to a passenger cabin may be releasably attached to an aeroplane. It is proposed to embody an arrangement by which the separation may be adjustably retarded and to connect the two by elastic couplings. It is claimed that the arrangement acts as a safety device for aircraft.

395,259. *Improvements in or Relating to the Control of Aircraft.* Airspeed, Ltd., and Tiltman, A. H., both of Piccadilly, York, Yorkshire. Dec. 29th, 1932. No. 36,771.

The specification describes a method of applying a bias to the control gear of an aeroplane, such as would be required to the rudder gear of a twin-engined aeroplane with one engine stopped, to relieve the strain on the pilot.

In the case of the rudder, the arrangement consists of a spring connected to a strap, both lying normally immediately over the rudder bar. One end of the strap is connected to the fuselage, and one end of the spring to one end of the rudder bar. A pulley-and-cord arrangement connected to the end of the strap, connected to the spring, enables this point to be displaced in either direction relative to the rudder bar, enabling a controllable bias to be put on the rudder bar in either direction. A modified but generally similar arrangement is proposed to place bias on the other aircraft controls.

395,689. *Improvements in or Relating to Gyroscopic Stabilisation Devices for Rotatable Bodies.* Messgerate Boykow, G.M.B.H., 2a, Fontanestrasse, Berlin-Lichterfelde-West, Germany. Assignees of Boykow, J. M., of the same address. Convention date (Germany), Jan. 8th, 1931.

Gyroscopic stabilising devices for aircraft, etc. The axle of the working gyroscope frame, mounted on the body to be stabilised, is coupled with said body by means of an inelastic damping device which is brought into operation whenever the frame tends to turn relatively to the body, and a reposition motor on the body adopted to be controlled according to the relative position of the axle of the frame and the body, the gyroscope being free to precess within the frame. The claims concern a hydraulic brake, methods of connecting switch gear, etc.

396,264. *Improvements in Aeroplanes.* Apolloniow, P., and Chick, S. L., both of 409, East 70th Street, New York, New York, U.S.A. Convention date (U.S.A.), Dec. 22nd, 1931.

It is proposed to construct a safety aeroplane which may be made to land safely even if it should develop engine or control trouble while in flight. It is also claimed that the aeroplane will be unable to spin or nose dive.

A large flap is hinged to the rear of the top surface of the wing and is arranged to open upwards. Air is collected by pipes from the gap thus formed and is carried round and directed on to points adjacent to the bottom of the rear end of the fuselage or to the botom of the front end of the fuselage, by

which means it is stated that the machine can be righted to a horizontal position when the occasion demands.

396,547. *Improvements in and Relating to Automatic Steering Systems.* The British Thomson-Houston Co., Ltd., Crown House, Aldwych, London, W.C.2. (Assignees of Alexanderson, E. F. W., 8 Adams Road, Schnectady, County of Schnectady, State of New York, U.S.A.) Convention date (U.S.A.), July 15th, 1931.

A method of automatically steering moving craft is described which utilises a combination of indications given by a compass and by received radio waves directly emitted along the course to be followed by the craft and to control the craft, means whereby to cause the craft to deviate from the course determined by the compass in a manner determined by the radio waves.

The patent diagram shows an arrangement operated by electrical means, and the indications given by the compass and by the radio waves result in variations of electro-motive forces the combination of which operate electrical apparatus which controls the rudder.

396,656. *Improvements in Wings for High-Speed Aircraft.* Caproni, G., 15, Lungotevere Arnaldo da Brescia, Rome, Italy. March 15th, 1933. No. 7,817.

A small " air breaking " or pilot wing is placed in front of the ordinary wing of an aircraft flying at very high speeds in order to reduce the resistance to their advancement. The said device is based on the consideration that at the said high speeds the air operates almost in the same manner as a solid substance, so that an auxiliary, wedge-shaped wing placed before the ordinary wing facilitates the penetration of the latter, thus ensuring better general efficiency in very fast machines.

The patent diagram shows a diamond-shaped body in front of and in line with the wing. The streamlines are shown as being separated by this body and as passing above and below the wing.

Aeroplanes, General

393,069. *An Improved Aerial Machine.* McLean, R., 28, Deramore Gardens, Ormeau Road, Belfast, Northern Ireland. May 5th, 1932. No. 12,986.

A flying machine arranged to rise and to be propelled by means of a combined series of suitably constructed collapsible cone-shaped wings or propeller blades which are constructed to expand and contract, or open and close, for propelling purposes at each side of the machine. A large parachute is also incorporated in the device, and elevators and steering mechanism is also provided. Circular and straight fixed planes are arranged so that, when propelled forward, they create a complete vacuum above them.

393,482. *Improvements in or Relating to Flying Machines.* Prosdocimi, G. A., 11/13, Via San Carlo, Bologna, Italy. Nov. 8th, 1932. No. 31,522.

The specification relates to flying machines having louvred wings rotating vertically in opposite directions to each other, the wings being rotated continuously about a common axis composed of two stub shafts rotating in opposite directions, the wings acting as supporting or propelling surfaces. Means are provided by which the spreading and folding of the louvres may be effected as the wing rotates. There is a further claim in which the planes comprise a rigid front zone for support formed by movable elements, and a flexible zone for propulsion, formed by a single surface.

Aeroplanes, Construction

392,905. *Improvements in Fuselage Bodies for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. Nov. 23rd, 1931. No. 32,397.

This refers to fuselages in which the skin participates with the structural members in taking the stresses imposed on it in flight. It is pointed out that in the normal fuselage of this type that the stressed skin may fail at a load much under its normal failing stress, owing to the production by the stresses of wave formation in the plating, and that consequently it has been necessary in the past to make the plating excessively thick, causing a serious increase in the weight of the fuselage.

The invention refers to stressed skin fuselages comprising a series of polygonal transverse frames spaced at intervals apart along the length of the fuselage, longitudinal members connected to the corners of the frames and a skin secured to the exterior of the longitudinal members and arranged in a series of flat panels bounded by adjacent longitudinal panels. This construction is claimed to produce a fuselage in which the skin can be highly stressed, leading to a saving of weight. It is claimed that this construction makes it unnecessary for the skin to be thick enough to be stable under wave-making compressive forces, and that tensile forces need only be considered and also that, in certain cases of loading, the forces acting in the tension field of one panel are balanced by those acting in tension fields of adjacent panels.

The patent drawing shows a fuselage constructed in this manner with the longitudinal members increased in number in the foremost panel, and there are also drawings of appropriate lattice transverse frames constructed in accordance with the specification.

396,025. *Improvements in Airplane Fuselages.* Rumbowicz, W., Mokotow, Lotnisko, Warsaw, Poland. Convention date (Poland), March 11th, 1931.

It is proposed to eliminate the blind area behind and below the fuselage in military aircraft by bifurcating the fuselage behind the rear gunner's station. The drawing shows a tractor type two-seater fighter constructed in this manner. The two bifurcations are shown as continuations of the side members of the fuselage and are continued straight back to carry the tail members, leaving a space between them through which the rear gunner could fire.

395,194. *Improvements in or Relating to Aircraft Bodies and the Like.* E. G. Budd Manufacturing Co., 2500 Hunting Park Avenue, Philadelphia, Pennsylvania, U.S.A. Sept. 15th, 1932. No. 25,686.

This refers to monocoque fuselages covered with skins of corrugated material and it is proposed to construct such fuselages with corrugations only on the top and bottom surfaces, leaving the side surfaces smooth. The drawing shows a fuselage constructed in this way with partial corrugation. The corrugations are shown as being concave.

395,533. *Improvements in or Relating to Girders, Beams, Spars and Like Structural Members.* Dornier Metallbauten, G.M.B.H., and Dr. C. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Oct. 28th, 1931.

A method of constructing aircraft spars. The spar consists of two bars or flanges of approximately rectangular cross-sections, connected by webs connected to two or more ridges projecting from the adjacent surfaces of the flanges. These webs may be more than two in number, each connected to its own ridges. The

webs may decrease in number from the fixed to the free end of the spar. The beam may be tapered by milling off the surplus metal projecting beyond the webs, the innermost webs being continued throughout the length of the beam. If the distance between the top and bottom boom is decreased from the fixed to the free end, it is stated that the method of construction enables a cantilever wing spar to be made with approximately uniform strength.

The drawings show spars possessing inside ridges on the flanges to which the webs may be attached, the outer webs being cut off at suitable points and the flange being milled away accordingly. This milling is shown either as a continuous taper or as being done in steps.

396,347. *Undercarriage for Flying Machines.* Messerschmitt, 24, Gentnerstrasse, Augsburg, Germany. Convention date (Germany), April 19th, 1932.

Suspended undercarriage, intended to offer very little resistance to the air. The patent consists in providing for each wheel a single spring stay projecting out of the machine only to the extent necessary for resilience, the wheels being mounted on stub axles attached direct to the spring struts, and, together with the lower portions of the struts, enclosed in a streamline casing. It is suggested that the struts be fitted with guides to take the rotational moments set up while landing, and that the sprung portions of the strut be located inside the casing of the flying machine.

Multiple wheels are referred to, and claims are made with regard to methods of attachment of the struts to the aeroplane.

394,452. *Improvements in Control Surfaces of Aircraft.* A.T.S. Co., Ltd., 5 and 6, Clement's Inn, Strand, W.C.2, and Martin, B. L., St. Wulstan's, Warlingham, Surrey. March 31st, 1932. No. 9,250.

This describes a special construction of ailerons and other aircraft control surfaces, the object being to obtain the necessary torsional stiffness and, at the same time, to reduce weight. Instead of fitting additional spars or other members on the control member to obtain stiffness, it is proposed to use a special front spar which may be of triangular or polygonal form in section, each of the faces of the spar being braced diagonally, or by sheet metal. In the drawing, a triangular spar is shown suitable for an aileron and a quadrilateral type for an elevator.

396,609. *Improvements in or Relating to Aircraft Landing Gear.* Dornier Metallbauten, G.M.B.H., and Dr. Ing. Claude Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Feb. 19th, 1932.

A form of folding chassis for aircraft. The first type described shows a chassis mounted on a monoplane wing and folding inwards. The folding is carried out by means of cords and pulleys and there is an inwardly directed diagonal strut to take lateral loads which is folded by means of a separate system of cords and pulleys. Means are provided for locking the chassis when in landing position, and the chassis carries a shield which covers the hole in the wing when the chassis is folded.

A modification is described in which there are additional fore and aft diagonal struts arranged to be folded, and there is a further claim for locking the chassis in the landing position by means of notches in pivotally-mounted beams or bars which may be acted upon by springs.

393,445. *Improvements in or Relating to Aircraft Landing Gear.* Dornier Metallbauten, G.M.B.H., and Dr. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date, Oct. 28th, 1931.

In the type of landing chassis described, the wheels are carried on struts which project downwardly and outwardly from the fuselage, the struts being arranged to pivot on a member at or near the outer skin of the fuselage, the shock-absorbing device being mounted inside the fuselage. This arrangement is stated to overcome the usual disadvantage of this type of chassis when the internal mechanism hampers the interior of the fuselage. The drawing shows a chassis when the wheel struts are attached to horizontal levers lying across the bottom of the fuselage and connected to shock-absorbing devices carried up the sides of the fuselage. It is stated that when there is a shaped cover for fairing surrounding a box-shaped fuselage, the shock-absorbing mechanism can be accommodated in the space between the two.

394,289. *Improvements in and Relating to the Manufacture of Force-Transmitting Constructional Parts for Aircraft, More Particularly for Aeroplanes.* Shevlin, J. T., 15, South Street, London, E.C.2. Feb. 23rd, 1933. No. 5,613.

This specification is concerned with the joining of the members of the structural portions of steel aircraft by soft soldered joints. Means are described by which it is stated bending moment stresses can be avoided on such joints so that the main force on the soldered joint is mainly shear. Where very thin sheet is used, this may be reinforced with paper or cardboard—the latter being removed when the construction is complete. It is proposed to use a solder having a relatively low fusing temperature, but when a plurality of joints lie in close proximity to each other the joints may be soldered progressively with solders having varying fusing temperatures from high to low.

Aeroplanes, Military

393,504. *Disappearing Nacelle for Aircraft.* Potez, H. C. A., Meaulte (Somme), France. Convention date (France), Dec. 21st, 1931.

The specification describes an arrangement for enabling a gunner to fire underneath the body of an aeroplane. A body, normally housed inside the fuselage, is arranged below the fuselage, is pivoted at its front end, and is controlled below the fuselage by two arms which enter forked brackets inside the fuselage—space is allowed so that the gunner can fire in the horizontal plane. The body is controlled by springs, in addition to a locking device, so that when the gunner enters the body, having released the locking device, the gunner's weight overcomes the springs and the body descends automatically to the firing position. On the gunner leaving the body, the latter returns automatically to the housed position and can be relocked in place.

Autogiros

393,976. *Improvements in or Relating to Aircraft having Freely Rotative Wings.* de la Cierva, J., Bush House, Aldwych, London, W.C.2. Dec. 16th, 1931, No. 34,867, and July 30th, 1932, No. 21,551.

This specification refers to autogiros of the type in which the rotor is used for the control of the aircraft in its normal flight manœuvres, as well as for sustentation. Control is effected by varying the inclination or the position of the rotor axis with respect to the aircraft body. Specification No. 264,282 is referred to. Means are provided for obtaining stability, whether the controls are locked or free. The controlling movements of the rotor may be damped or may be biassed by means of springs. Methods of speeding up the rotor by means

of a drive from the engine are described, and there are 47 claims concerning these devices.

Balloons

396,277. *Improvements in Balloons.* Antoni, U., 31, Old Compton Street, London, W.1. Convention date (France), Dec. 22nd, 1931.

Balloons for use for advertising purposes. The balloon is of the elongated form, and has laterally projecting wings and a flexible tail. The balloon carries a box-shaped frame secured to its underside. To the underside of this frame there are attached illuminated signs by means of which letters or figures may be shown. The balloon is tethered to the ground when in use.

Engines and their Accessories

392,940. *Improvements in Engine Mountings.* Trott, R. S., 704, Equitable Building, Denver, Colorado, U.S.A. Nov. 16th, 1931. No. 31,670.

The specification deals with the type of engine mounting in which a resilient support is introduced for the purpose of absorbing the variation of the torque reaction in an internal combustion engine. Various means are described for carrying this out, and there are a number of claims concerning different arrangements of the mounting. Although principally concerned with automobile practice, an aero engine mounting on this principle is described.

394,643. *Improvements in Cooling Radiators for Heat Motors.* Societe Anonyme de Representation et de Commission, 33, Rue des Dames, Paris, France. Convention date (France), Sept. 22nd, 1930. Void.

The radiator described is characterised by elements consisting of concentric tubes leaving between them an annular space for the passage of the fluid to be cooled, the air passing both inside and outside the tubes. The tubes may be ribbed spirally both inside and outside so that a helical path may be given to the cooling fluid or to the air. Various methods of forming such tubes into complete radiators are described and also various methods of adopting them to, and mounting them on, the fuselage of an aeroplane.

396,622. *Improved Systems for Driving Propellers.* Aktiebolaget Milo, Kungsgatan 32, Stockholm, Sweden. Convention date (Germany), Jan. 20th, 1932.

This describes a method of connecting gas turbines and propellers and has particular reference to marine propulsion. The description first refers to double rotation turbines in which one shaft drives the compressor and the other shaft the propeller by means of a speed reduction gear, but various methods of driving these components by differing combinations are described and illustrated in the diagram.

Helicopters

394,402. *Improvements in Propellers of Helicopters.* Trojani, P., 11b, Via Ruggiero Bonghi, Rome, Italy. Convention date (Germany), Jan. 8th, 1931.

This concerns the arranging of a pitch-controlling device to helicopter blades so as to compel the blades to take up an equal pitch so that all the blades always rotate automatically through equal angles round their axes and on their joints, which consist of a ball or universal joint. It is assumed that the blades have stabilising planes or like automatic incidence controlling gear, and a limiting and damping arrangement is provided for the horizontal rotation of the blades.

An arrangement of linkages is claimed by which the pitch controlling gear on one propeller can be made to control another propeller without duplicating the gear.

Kites

396,459. *Improvements in Kites.* Pemberton, T. J., 25, Blenheim Gardens, N.W.2, London. Feb. 12th, 1932. No. 4,211.

The kite described is of the tailless type and belongs particularly to that class in which the fabric is shaped so as to produce an apex, or its approximation, at a point some distance forward of the frame with the point of the apex nearer to the top of the kite than the bottom. The kite is shaped to form a five-sided figure with a frame consisting of one central rod and two others forming a cross.

Piloting

396,378. *Apparatus for Training Air Pilots on the Ground.* Whiting, J. R. S., Bevers Hill, Farnham, Surrey. Jan. 22nd, 1932. No. 1,941.

An apparatus consisting of a dummy aircraft fuselage mounted inside a hollow sphere. The dummy fuselage is fitted with a pilot's seat and controls as in an actual aircraft, while the interior of the sphere is painted with scenery such as might be seen in flight. This scenery may be reproduced photographically. This hollow sphere is connected to, and is moved by, the controls in such a way that movement of the controls produces the illusion that the craft is responding to the controls substantially as in flight.

396,537. *Mechanism for the Ground-Training of Air Pilots.* Air Service Training, Ltd., Flight Lieut. H. F. Jenkins and Berlyn, R. C., all of Hamble, near Southampton, Hampshire. June 25th, 1932. No. 17,975.

The device described is one by which the compass or its indication may be changed by the instructor so as to teach the pupil how and when to correct his course. This object may be attained by using a movable magnet affecting the reading of the compass and operated by the instructor. An apparatus simulating an actual compass may be used, and various magnet combinations are described.

396,538. *Mechanism for the Ground-Training of Air Pilots.* Air Service Training, Ltd., Flight Lieut. H. F. Jenkins and Berlyn, R. C., all of Hamble, near Southampton, Hampshire. June 25th, 1932. No. 17,976.

It has been found that with the aircraft headed on certain courses the movable portion of a magnetic compass swings slightly as the speed of the aircraft is varied. Owing to the wrong indication thus given, the pupil is liable to think he has deviated from his course and consequently has to be taught the effects of speed changes on his compass. This is especially important when blind flying.

The specification describes means for temporarily deflecting the movable element of a compass-like indicator and for allowing it to return slowly to its normal position, such means being connected differentially with a lever resembling an engine throttle lever actuated by the pupil, and a control column to be operated by the pupil.

The bowl of the compass-like indicator is filled with a damping liquid which can be given a rotary motion in one or the other direction, hence deflecting the movable portion of the indicator This action is produced by a double-acting piston in a cylinder adapted so as to produce the rotary movement of the liquid by forcing liquid into and out of the indicator bowl in the appropriate direction. This double-acting piston is connected suitably to the driving throttle lever and control column by a system of leverage, and is arranged so that the flow can be varied, reversed, or stopped as desired.

396,539. *Mechanism for Controlling Pitch Indicators for the Instruction of Aircraft Pilots.* Air Service Training, Ltd., Flight Lieut. H. F. Jenkins and Berlyn, R. C., all of Hamble, near Southampton, Hampshire. June 25th, 1932. No. 17,977.

Mechanism for controlling pitch indicators for use in the ground training of aircraft pilots. The patent describes an apparatus by means of which an instructor may move a control column backwards or forwards to bring about a dive or climb of the imaginary aeroplane. This movement would be shown on a pitch indicator and the pupil should perform the necessary movements of his control column to restore the imaginary aeroplane to the horizontal, the restoration being shown on the pitch indicator.

The diagram shows a pitch indicator connected by a V tube to a reservoir, the position of the level of the liquid in the tube of the pitch indicator being capable of being varied by an alteration of the height of the reservoir. The height of the reservoir is capable of being varied by either of two control columns which are connected to the movable reservoir by a system of pulleys, cords, and a weight. There is also a connection to an imitation throttle lever by means of which the movable element can be temporarily disturbed.

396,540. *Mechanism for Controlling an Indicator Device for the Instruction of Aircraft Pilots.* Air Service Training, Ltd., Flight Lieut. H. F. Jenkins and Berlyn, R. C., all of Hamble, near Southampton, Hampshire. June 25th, 1932; No. 17,978. June 25th, 1932; No. 17,979. June 25th, 1932; No. 17,980.

This specification describes an apparatus by means of which ground instruction may be given to a pupil in regard to diving and climbing or to turning and/or sideslip. The apparatus consisting generally of an indicator, the movable element of which is differentially connected to two controls, so that movement of either control in one or another direction can effect movement of the element without the other control being disturbed. Reference is made to Specification 378,172. One control would be operated by the instructor and the other by the pupil.

The diagrams show two control columns connected differentially to the indicator by means either of a lever system or of a system of cords and pulleys, in addition to a weight or spring, for the purpose of biassing the movable element in one direction.

A further diagram shows the application of the principle to two rudder bars.

REVIEWS

The Stresses in Aeroplane Structures

By H. B. Howard, B.A., B.Sc., F.R.Ae.S. Sir Isaac Pitman and Sons. Price 20s.

This treatise is of considerable importance. Mr. Howard has been engaged for many years in the investigation of stresses on aeroplane structures and is recognised as an authority on the subject, and his book will be found to contain a full account of the modern methods of calculating the strength of aircraft.

The first two chapters are introductory and contain the ordinary matter on stresses and strains and on the bending of beams, the third chapter deals with struts and is followed by chapters dealing with the cases of laterally loaded struts that occur so commonly in aircraft. The method, devised by the author, of the

use of polar co-ordinates for solving the problems that arise in connection with such struts is fully explained and a new extension of the method to tapered struts is included. There are other chapters dealing with strain energy methods, torsion, etc., and these are followed by further chapters dealing with the loads on an aeroplane, main plane, and other aircraft structures.

It is unquestionably desirable that the value and distribution of the stress in all members of an aircraft structure under conditions of flight should be known as accurately as possible. But in order that this may be done it is necessary firstly that the loads which may occur in flight should be accurately known, and secondly, that the mathematical equipment for calculating the effect of these loads on the structure should be adequate. To the latter problem Mr. Howard has made many contributions, and he has simplified the complicated mathematical work involved by his very ingenious method of polar co-ordinates.

Unfortunately the knowledge of the loads on an aeroplane in flight is still incomplete, in the author's words, " so diverse are these (loads) that it is impossible to state with complete precision the strength which each particular part should have." It has therefore become necessary to state a number of standard conditions, and to calculate the strength of the structure in relation to these and to ignore the others.

There is one justification, and one only, for a procedure of this sort, and that justification exists if it can be shown that aircraft whose strength has been passed as adequate when calculated in this way are structurally safe in flight. That this is so in the case of British aircraft, no one who knows the circumstances will doubt, but this statement is equally correct if applied to, say, war-time aircraft, many of which were stressed by methods which would now be considered crude.

A greater knowledge of the effect on a structure of applied loads should be reflected in either one or two directions. Either the structure should be stronger for the same total weight, owing to better distribution of the material, or the more complete information should enable the load factors to be reduced, resulting in a reduction of the structure weight. Actually the modern tendency is to increase aircraft load factors.

The fact is that our knowledge of the effect of load on a structure has outrun our knowledge of the amount and distribution of the loads on an aeroplane in flight, and that further work on this latter subject is urgently wanted in order that the balance may be restored.

This book should be possessed by everyone interested in the subject with which it deals, and will be found to be a most useful text book by those engaged in stress work.

Seaplane Solo

By Francis Chichester. Messrs. Faber and Faber. 10s. 6d.

This is a story of adventure. Mr. Chichester has made up his mind to fly the Tasman Sea, which lies between New Zealand and Australia. He starts the flight with a seaplane of insufficient range to make the direct flight, so it is necessary to pick up two small islands more or less on his route. This he succeeds in doing. On the second island his machine is capsized by a squall, but he succeeds in completely rebuilding it with the aid of volunteer helpers, and eventually manages to reach Australia with a failing engine and a punctured float.

The author writes quite frankly about himself and the reader can get some inkling into the fears and anxieties which accompany flights of this sort. The knowledge of inevitable doom awaiting if the expected island does not appear, the joy and sense of achievement when among the gathering clouds a rocky outline becomes unmistakable, and the struggles with unsatisfactory equipment, failing instruments, etc., are all described and described well.

But the great feat was the rebuilding of the seaplane on Lord Howe Island, and the description of how it was done is an example of what can be accomplished by a mixture of horse sense and enthusiasm. Mr. Chichester would have saved himself an enormous amount of trouble if he had spent a few weeks in a factory watching seaplanes being made, but he would have written a much less interesting book.

It is not clear how much time was spent on Lord Howe Island, but Mr. Chichester's knack of descriptive writing comes in useful in describing the life on the island and the people who inhabit it. The book is worth reading for his fishing stories alone.

As a Christmas present to air-minded youth the book is ideal.

British Standard Nomenclature of Timber for Aircraft Purposes

British Standards Institution. Price 2s. 2d.

This book contains a complete list of timbers which might be used in aircraft together with their botanical names, sources of supply, and notes on their suitability. Whether such a work is valuable is dependent on its being reasonably complete. It is difficult to check whether this really is so, but it has passed easily such tests as it has been possible to apply. Those interested in aircraft timber will find it a valuable work for reference purposes.

British Glossary of Aeronautical Terms

British Standards Institution. Price 5s.

This, the 1933 edition of this Glossary, has had added to it the various terms which have arisen since the last edition was published and it is unquestionably the standard of aeronautical technical English. But it is rather puzzling to find that, as before, the otherwise unknown word " aerodyne " is inserted and defined specially to help in the definition of other terms; surely this is unnecessary. It has been found possible to define parachute without using this word (by the way, is a parachute an aerodyne?) and it should also be possible to define other words without it.

The book is one of great value to all those engaged in aeronautics. However much one may be acquainted with the terms used in one particular branch of the subject, there are many terms in current use in other branches which require definition when met with, and all such information is given here, and is in many cases illustrated by diagrams.

In addition to the technical terms the book contains the standard mathematical notation, and it is hoped that those writing technical works will adopt this notation exclusively. Failure to do so leads to serious loss of time when a technical work is consulted.

Marine Aircraft Design

By William Munro. Price 20s. Publishers: Sir Isaac Pitman and Co.

This book deals with the design of seaplanes and flying boats and contains a quantity of interesting information on this subject. That part of the subject which is common to all aircraft is, generally speaking, not dealt with, though the book contains a chapter on Wing Design by Mr. B. S. Shenstone.

A book dealing exclusively with seaplanes and flying boats has been badly wanted, and it is only those who have designed aircraft of this type who realise the complications involved and the judgment required in making the numerous compromises necessitated by the various differing conditions.

On the whole, Mr. Munro has dealt with his subject well. He has had, obviously, considerable experience with this type of aircraft and his descriptions of design methods, notes on cost of manufacture as affected by design, and on

the numerous special requirements of seaplanes, such as walkways, mooring and towing equipment, slinging gear, beaching, etc., are valuable. In many cases he gives an analysis of the weights of components, a subject on which information is usually scarce, and his notes on methods of calculation, stressing, etc., are useful.

In certain cases the data are inadequately explained. What, for instance, are the two R's which head columns in the table on page 35? Several of the symbols used on this page are apparently unexplained, and there should never be any doubt as to the meaning of symbols. Again, on page 34 reference is made to drainage holes on Fig. 56. These are not obvious and should be indicated by words on the diagram. In Chapter I the aspect ratio of wings is referred to and methods of calculating this are given, but the normal method that this ratio is equal to span squared, divided by area, is left out. In most cases it is preferable to calculate areas and moments by means of a planimeter rather than by the methods given.

It is certain that the author could say a good deal more than he has on the question of hull design. Sets of lines for several hulls with curves showing their resistance on the water, arranged so as to show the effect of various modifications in shape, would have added much to the value of the work.

The book, as it stands, contains a quantity of useful information on its subject, and can be recommended to those who wish to study seaplane design. But it is quite certain that Mr. Munro can do much better and it is to be hoped that he will have the opportunity of doing so in a future edition.

Aircraft Performance Testing

By S. Scott Hall, M.Sc., D.I.C., A.F.R.Ae.S., and T. H. England, D.Sc., A.F.C., A.F.R.Ae.S. Published by Sir Isaac Pitman and Sons, Ltd. Price 15s.

The subject of performance testing of aircraft has not so far been the subject of a text book, and an authoritative treatise on the subject is overdue. This want is adequately fulfilled by this book, which deals with the whole matter both from the point of view of the pilot who has to carry out the tests and of those who have to reduce the figures obtained by the pilot to standard conditions.

The subject is discussed in great detail, methods of weighing, instruments, partial climbs, speed determinations, fuel consumption and other tests, stability, spinning, diving, and tests for the certificate of airworthiness are dealt with, together with other cognate matters, and the book concludes with chapters on theory and performance analysis.

Great credit is due to the officials at the Air Ministry test stations of Martlesham Heath and Felixstowe for the development of the methods of test analysis now in use, which have resulted in an approximate elimination of weather conditions as a variant in the performance results, but there appears to be still some doubt as to the figure to be taken for the engine horse-power.

The obvious method of dealing with this would be to use some form of torque measuring device, which, combined with the known speed of the engine, would enable the power to be ascertained directly. But the mechanical difficulties in the production of such an apparatus have not yet been satisfactorily overcome and it has been found necessary to use a method which has in the authors' words "been established as a result of examination of all available data." This method, which assumes that the engine power varies as a function of $(\text{pressure})^{\frac{3}{4}} \times (\text{density})^{\frac{1}{4}}$, has resulted. Such a formula is not likely to be more than an approximation for all engines under all conditions, but it represents possibly the best that can be done pending the development of a torque measurer. Some years ago it was usual to add a correction for engine friction on the assumption that this was constant for constant revolutions, but independent of the horse-power developed, but this has now been dropped.

The references to testing for certificates of airworthiness are of considerable interest, especially with regard to spinning, for which no requirements appear to be laid down in official publications unless the aeroplane is fitted with slots. Why this should be so is hard to say, but it is interesting to note that tests are, in practice, carried out on spinning, and, presumably, a machine reported as unsatisfactory in this respect would be refused a certificate of airworthiness. This matter should receive more attention from the authorities, as it is probable that more fatalities have occurred from the accidental spin than from any other cause, and the development of a type which is either non-spinnable or which possessed an extreme reluctance to spinning would be of great importance. The ease of recovery from a spin becomes of less and less importance the greater the reluctance of an aeroplane to go into one.

The most unsatisfactory test for a certificate of airworthiness seems to be the one concerned with the height cleared over an imaginary screen. All these getting off tests depend greatly on the condition of the surface of the aerodrome, which cannot be standardised, and on the amount of practice the pilot has had with the particular aircraft. The best results in the screen test appear to be obtained by holding the machine on the ground until the last possible moment and then zooming, which is a method of taking-off which no pilot would normally use. It would seem desirable to devise an alternative test which would be free from such objections. It would seem that such tests would be reduced to a function of the getting-off speed of the aeroplane, the weight and air resistance of the aeroplane, and the thrust of the propeller.

Messrs. Scott Hall and England have done their work very well and have produced a most useful text book.

The Modern Diesel

Published by Iliffe and Sons, Ltd. Second Edition. Price 3s. 6d.

This book belongs to the class of text books written for readers who possess little or no technical knowledge, but who are desirous of understanding generally how an engine works. It fulfils this purpose admirably.

The compression ignition engines referred to are divided into three main classes—road transport, aero and marine—in each case a number of types are described and illustrated and, where necessary, diagrams and curves are given. These illustrations, etc., are excellently produced and show clearly the internal construction of the engines. It is interesting to note that there has been an average increase of mean effective pressure in industrial engines since the last edition was published, amounting to some 15 or 20lbs. per square inch. This figure is some indication of the improvement which is taking place in the design of such engines.

In the chapter on road transport engines in service there is some doubt as to whether the figures given relate to useful load or to the total loaded weight of the vehicle. In one case a figure of 197 ton miles per gallon is quoted for a lorry weighing 19 tons, the speed given being 25 miles per hour. It is hoped that such speeds are not common with such weighty vehicles.

Considerably more space than usual is devoted to aero engines and eleven different types are illustrated and described, including the Bristol "Phoenix," the most recent member of the group. This part of the book is of distinct interest to those engaged in aeronautics, as all types of compression ignition aero engines are illustrated and described in a manner convenient for reference.

The book has an introduction by Mr. Alan Chorlton and it is interesting to note the numerous extracts which have been taken from papers read before this Society.

The 565th Lecture delivered before the Royal Aeronautical Society since its foundation, January 12th, 1866.

PROCEEDINGS

TWENTY-FIRST WILBUR WRIGHT MEMORIAL LECTURE

The Twenty-First Wilbur Wright Memorial Lecture, entitled " Training the Airplane Pilot," was delivered before the Society on Tuesday, May 30th, 1933, at 6.30 p.m., at the Royal Institution, 21 Albemarle Street, W.1, by Colonel F. P. Lahm, Air Corps, U.S. Army.

Mr. C. R. Fairey (President of the Society) in the chair.

The PRESIDENT: Before introducing Colonel Lahm he had, in accordance with custom, a few statements to make, particularly relating to the awards made by the Council for the year 1932-33. First, he had to announce the award of the Society's Gold Medal. It was, as they knew, the highest honour which the Society could confer and was one that was very jealously guarded. It was interesting to recall that the only recipients so far were Messrs. Wilbur and Orville Wright, the memory of one of whom they were honouring that night, Professor Chanute, Professor Bryan, Mr. E. T. Busk, Dr. Lanchester and Professor Prandtl. He had the greatest pleasure in announcing that the Council had unanimously made a seventh award of the Gold Medal to Sir Richard Glazebrook, K.C.B., F.R.S., a Fellow of the Society, for his work as Chairman of the Aeronautical Research Committee since its foundation in 1909. For the twenty-four years Sir Richard guided the destinies of that famous committee. Under him it grew to be the most renowned institution of its kind in the world. Its reports were models of what scientific reports should be, and he need not tell that audience that its work had had a most profound influence on the cause of aviation, and they believed would continue to do so. Sir Richard's great scientific achievements were probably known to everybody present. He bore one of the most famous and most honoured names in the world of science, and the President knew that he spoke for them all in extending to Sir Richard their thanks and congratulations. He was sure they would agree that the Council had never made a more fitting award.

The Society had three other gold medals—the Simms Gold Medal, the Wakefield Gold Medal and the Taylor Gold Medal. The first named was awarded for the best paper in any year read before the Society on any science allied to aeronautics, and was open to members and non-members. That year it had been awarded to a non-member, Mr. P. Salmon, M.I.Mech.E., M.I.A.E., for his paper on " Catapults," which was read before the Society on 25th February last. Mr. Salmon's work on the subject and his knowledge of it fully entitled him to this recognition from the Society.

The Wakefield Gold Medal, which was awarded for the invention or development of any device making for the safety of aircraft had been very fittingly awarded to Mr. L. G. Frise, B.Sc., a Fellow of the Society, for the invention of his well-known aileron.

The Taylor Gold Medal, for the most valuable paper read during the previous session, had been awarded to Dr. G. V. Lachmann, an Associate Fellow of the Society, for his paper on " Control Beyond the Stall," read before them on 17th December, 1931. He need not remind them that Dr. Lachmann was the co-

inventor and developer, with Mr. Handley Page, of the most famous of all safety devices—that of the slotted wing and slot control.

Hardly of lesser importance was the Silver Medal of the Society, which was intended for technical achievement rather than scientific. Among the previous recipients would be remembered Mr. S. F. Cody, Mr. Ricardo, Professor Melvill Jones, Captain Wilkinson, Mr. R. J. Mitchell, Mr. P. J. Ralli, Mr. B. N. Wallis, Dr. Townend, and the late Sir Henry Royce. That year the Council had awarded three Silver Medals. The first award was made to Senor J. de la Cierva, the inventor of the autogiro. Perhaps it was not inopportune to remind the audience that it was thanks to Mr. Wimperis, the Director of Scientific Research, that Senor de la Cierva came to this country, many years ago, and the greater part of the development of his invention was made here. There was no time to go into the details of that invention; they all had great hopes of it for the future, and he greatly regretted that Senor de la Cierva was unable to be present to receive his award.

The second award, a very popular one, was to Mr. A. H. R. Fedden, M.B.E., a Fellow of the Society, for his work on the air-cooled engine, which the President thought owed more for its development to Mr. Fedden than to any other man. His work had culminated in bringing to this country the world record for height, and, as they all knew, Mr. Fedden built the engine which made that achievement possible.

The third award went to Mr. D. L. Hollis-Williams, B.Sc., an Associate Fellow, for his design work on the monoplane which held the world's long-range record. Speaking from personal knowledge, he was pleased to say that this design which had taken the world's record was the first design with which Mr. Hollis-Williams had been wholly entrusted.

During the year the following awards were also made:—To Mr. D. L. Hollis-Williams jointly with Mr. A. R. Collar, B.A., B.Sc., the R.38 Memorial Prize—which was founded in 1923 for the best paper received by the Society on some subject of a scientific nature in the science of aeronautics, preference being given to papers relating to airships—for their paper on "The Motion of an Airship under Certain Conditions."

The Busk Memorial Prize—awarded for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes or seaplanes—was awarded to Mr. H. Constant, M.A., an Associate Fellow of the Society, for his paper on "Aircraft Vibration"—one of the most important papers on this subject which had been read for some years.

Finally, the Pilcher Memorial Prize—for the best paper by a student on heavier-than-air craft or any analogous subject—was awarded to Mr. F. W. Dowsett for his paper on "The Design of Aeroplane Controls and Control Systems."

He now came to three other important awards. As had already been announced, the Society had founded two new medals. The existing awards covered the science and the technical side of aviation. They had not had one to cover practical achievement. These medals were founded at the suggestion of Lord Amulree, when he was Secretary of State for Air. They were called the British Gold Medal for Aeronautics, and the British Silver Medal for Aeronautics, and would be awarded for outstanding practical achievements in the air. To commemorate a great pioneer in practical achievement the Gold Medal bore on one side a portrait of Sir George Cayley and his model aeroplane of 1804, and the Silver Medal correspondingly bore the design of the Henson and Stringfellow machines of the period 1840-48. The Special Committee to consider the award of these medals sat at a very opportune time, and they made three awards, the first to Captain C. F. Uwins, an Associate Fellow of the Society,

for reaching the world record height in a heavier-than-air craft of 43,976 feet on 16th September last. There was no need for him to dilate on the meaning of that achievement, said the President; a more fitting one could not have been found for the first award of the British Silver Medal for Aeronautics.

The next award of one medal each went to Squadron-Leader O. R. Gayford, D.F.C., A.F.C., R.A.F., and Flight-Lieutenant G. E. Nicholetts, A.F.C., R.A.F., who flew from Cranwell, in England, to Walvis Bay, in South Africa, non-stop, on February 6th-8th last, a distance of 5,309 miles. That was not the place to expand upon the achievement, remarked the President, except to acknowledge that the strain on the pilots engaged on this class of work was becoming greater—and possibly the work of the designer less—as the attack on the records proceeded.

The President said he had one more important announcement to make before introducing the lecturer. As they knew, every possible effort was made by the Council to raise and to maintain the standard of their examinations. The Education and Examinations Committee held many sittings, and repeatedly the qualification requirements were stiffened. It was with very great pleasure that he was able to announce that in March last they received from Sir John Siddeley—the then Chairman of the Society of British Aircraft Constructors, Ltd.—a letter in the following terms:—

21st March, 1933.

Dear Mr. Fairey,—The Society of British Aircraft Constructors have followed with great interest for some years the constant efforts which the Royal Aeronautical Society have made to make Associate Fellowship and Associate Membership of the Society very real qualifications.

They are satisfied now that each grade calls for such experience, training and technical knowledge that, other things being equal, an Associate Fellow or Associate Member of the Royal Aeronautical Society should be chosen for a post in the Industry in preference to one not holding one of these qualifications.

Yours sincerely,

(Signed) (Sir) J. D. SIDDELEY,

Chairman.

He thought that that was a very pleasant and fitting acknowledgment that the efforts of the Council and the whole Society to maintain a high standard of degrees were now being properly recognised.

Turning to the event of the evening, the President reminded them that many famous people had read the Wilbur Wright Memorial Lecture since its inauguration, some of whom were present that night, including Sir Richard Glazebrook, for so long Chairman of the Aeronautical Research Committee, Mr. Tizard, his successor, Mr. Griffith Brewer, a very old friend of the Wright brothers, and, he believed, the first Englishman to fly with them, Mr. Wimperis, the Director of Scientific Research, and Professor Bairstow, Zaharoff Professor of Aeronautics in the University of London. The Society were particularly fortunate in securing Colonel Lahm to lecture on the very fitting subject of training the aeroplane pilot. Was not one of the greatest discoveries of the Wrights the fact that one not only had to build a flying machine, but to learn to fly it? Before they attempted mechanical propulsion they spent years in learning to fly on a glider. They appreciated that fact as very few of the other experimenters had done. The Wright machine was not only the first aeroplane to fly by the dual system of control, but was the first training plane in which the pupil sat side-by-side with the master, felt the controls, and learned the actual art of flying from experience in the air. Among those very first pupils was Colonel Lahm, who, as long ago as the summer of 1909, at Fort Meyer, received his first instruction from Wilbur Wright himself. Colonel Lahm had since that

time been continuously detailed to aviation duty, culminating in his appointment as Brigadier-General from 1926 to 1930 to organise and command the U.S. Air Corps Training Centre at San Antonio, Texas. Here he had 450 Army officers, including air instructors, in his organisation. He had probably had wider experience in aeroplane training and organisation than anyone else in the United States. Colonel Lahm was now Military Air Attaché at the American Embassy in Paris, where his duties included active flying. He had flown from Paris to deliver the lecture that night, and in his hurry proposed to fly back the next morning. He was sure that they would agree that no better man could be found to deliver the lecture, and it was with the greatest pleasure that he introduced Colonel Lahm to the audience.

TRAINING THE AIRPLANE PILOT

BY

COLONEL F. P. LAHM, Air Corps, U.S. Army

1. Introduction

Allow me, in beginning, to express to you my appreciation of your kind invitation to appear as the Wilbur Wright lecturer before this society, which has the distinction of being the oldest aeronautical technical organisation in existence. I am doubly appreciative; first, because in my earlier activities in aeronautics I had the privilege of coming in contact with many of your most distinguished air enthusiasts. It was my pleasure to compete in 1906 in the first Gordon Bennett Balloon Race with the Hon. Chas. Rolls, Colonel Capper, Professor Huntington, Mr. Frank Hedges Butler, Mr. M. C. Pollock, and my very good friend Mr. Griffith Brewer. It was my good fortune at that time to view your country from the air in a flight which took me from Paris to the coast near Chichester to Flying Dale in Yorkshire, passing over such interesting and historical places as Stratford-on-Avon, Warwick Castle, and the moors of Yorkshire. It was my pleasure later to make an ascension from London with the Hon. Chas. Rolls, in a balloon put at our disposal by the Hon. Mrs. Asheton Harbord, who had been a fellow-passenger on my first trip in an airship a short time before, in France. I was entertained by Colonel Wm. Cody's plans for a heavier-than-air machine and his project for crossing the Channel in a boat towed by a kite. Under Colonel Capper's guidance, I had the privilege of visiting your aeronautical centre at Farnborough, limited at that time mostly to lighter-than-air activities.

It is always a pleasure to recall the names of my distinguished compatriots and friends, Orville and Wilbur Wright, the inventors of the airplane. It was my privilege to meet them first in 1907, in France, when they came to Europe to interest foreign and sometimes sceptical nations in the machine whose practicability they had fully established some two years earlier. The friendship established at that time has continued and grown through the intervening years, broken only by the unfortunate and untimely death of the elder brother in 1912.

With Orville Wright, at Fort Myer, I received my initiation in a heavier-than-air machine, in September 1908. In the autumn of 1909, at College Park, near Washington, I received my training as an airplane pilot from him whom we honour to-night—Wilbur Wright.

I consider myself fortunate to have sat at the feet of one of the fathers of flight, to have absorbed from him my earliest impressions of flying training; fortunate to have had the intimate relationship of instructor and student. His quiet manner, his even temperament, his unassuming confidence in himself and

his machine, were ever a help and an inspiration to a beginner attempting to master an art of which so little was known.

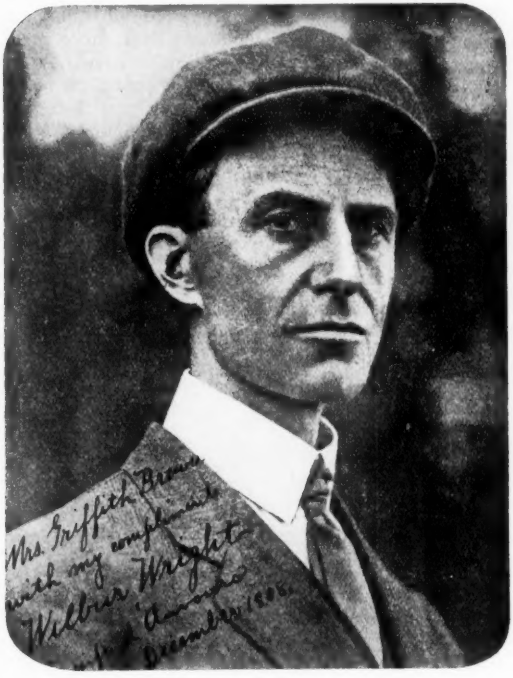

FIG. 1.
Wilbur Wright.

Fig. 2 shows the first controlled flight of a motor-driven heavier-than-air machine on December 17th, 1903, at Kitty Hawk, N.C. The pilot was in a prone position.

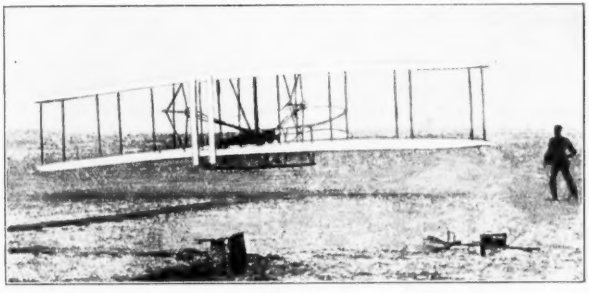

FIG. 2.
First controlled flight of a motor-driven heavier-than-air machine. December 17th, 1903. Kitty Hawk, N.C.

II. Early Training

Many of the earliest pilots were necessarily self-taught, gradually feeling their way, first running the plane on the ground, then short hops, then straight-away flights at low altitude, then gradually accomplishing the more difficult feat of making turns, after which there remained little more to learn—the pilot's training was complete after practising these manœuvres in the air. At one time the plan of giving land pilots their first instruction on seaplanes was tried, as it did not require the same accuracy to set a flying boat down on yielding water that it did to put a land plane down on the unyielding earth, and shock absorbers were not always sufficiently efficient to take the punishment they were likely to receive from the beginner in " trying to find the ground." This method was abandoned, however, as taking too much time.

Even during the war we find the Penguin in use—the machine with insufficient wing surface to lift or with the throttle so limited as to prevent the student using sufficient power to rise. So far as I know, this method has since been entirely abandoned as unnecessarily long and tedious.

It is interesting to recall some of the methods and implements used in pilot training in 1909, merely to show the progress in the intervening 24 years. The Wrights necessarily used the dual method of instruction, from the beginning, taking the student into the air at once, as the plane was not equipped with wheels for rolling on the ground. And even after the adoption of wheels in 1910, they continued the dual system which experience has since proven to be the more practicable. Their training flights were invariably at a low altitude, generally 20 to 30 feet, and as only the simplest manœuvres were executed, flying was as safe or safer at this altitude than at a higher one—in case of a forced landing due to failure of some part of the machine. With the introduction of more complicated manœuvres it became necessary to fly higher, so as to have altitude to recover before reaching the ground in case of a false manœuvre.

The one and only instrument we used in 1909 was a short piece of tape or string hanging from the cross-piece connecting the two landing skids and plainly visible to the pilot and pupil. If, in turning, the string remained parallel to the landing skid, the turn was correct, that is without skid or slip. The 30 h.p. plane used in my instruction had no landing wheels, consequently the take-off was made from a cradle with two tandem wheels running on a monorail. A pull on the elevator on reaching the end of the track raised the plane in the air while the cradle remained on the ground. Landing on the two long runners was comparatively easy, as the landing speed was low, and, from his open seat on the edge of the lower wing, the pilot could measure his distance from the in being compelled to wait while the mechanics rolled out two wheels to place under the wings, then pushed the plane back to the starting track to repeat the process of setting it on the cradle for the next take-off. To acquire flying ground with the greatest accuracy. There was a certain inconvenience, however, speed on the 60 ft. or more of track, the power of the engine was augmented by ropes running on pulleys from the plane to the end of the track, then to a heavy weight which, in falling, pulled the plane forward on the track, so that under the combined force of the engine and the falling weight a speed of something over 25 m.p.h. was acquired by the time the plane reached the end of the track.

Direct feed with no carburettor necessitated holding a gasoline-soaked rag over the intake in order to start the motor; while to stop it, one hand was removed from the controls long enough to strike a string overhead, thus releasing the compression in the cylinders—and all landings were necessarily made with a dead engine.

Elevator, rudder and aileron control were obtained by two levers, one in each hand, while one foot operated the spark advance—the only means available

for regulating the speed of the engine. Aerobatics as we know them to-day were not attempted, but the lack of surplus power and the clear visibility of the ground required and permitted an accuracy in the use of controls and in landing which reacted to the benefit of the student in contrast with the often over-powered plane of to-day and the location of the seats in a closed-in cockpit, far from the ground and with no view of the point of contact of the plane and ground.

The student sat at the middle of the leading edge of the lower wing; the weight of the instructor on his left balanced the weight of the motor on his right. The elevator was operated by two separate sticks, one in the pilot's left hand and one in the student's right hand, while the ailerons and rudder were operated by a single stick between the instructor and the student—thus in the instructor's right and the student's left hand. This was a cause of some inconvenience, as the student could fly alone only by attaching a weight to the left wing to compensate for the weight of the instructor. A fellow-student and myself overcame the difficulty by giving each other additional later instruction so that we learned the use of the controls as used in the outer or instructor's seat.

With the introduction of higher powered, more strongly constructed machines and more complicated manœuvres, came a change in the methods of instruction. Safety dictated a higher altitude, even for the simpler manœuvres. By 1915-16 we had reached the stage of more difficult tests such as landing to a mark either from a straight glide or from a spiral. To simulate landing in a restricted field, the student was required to glide in over an obstacle represented by a band stretched across the line of flight, the plane being brought to a dead stop within a given distance of the obstacle. To simulate rising from a restricted field, a rectangular area was staked out, the student took off from one corner and was required to climb to 1,000 ft., keeping at all times within the space over the outlined area. Cross-country training became a part of the curriculum; and while prepared landing fields were rarely to be found, the slow take-off and landing speed of the planes made it possible to use pastures, meadows, and other fields which to-day would hardly be considered suitable.

The World War gave a completely new aspect to aviation. A new weapon—the airplane—appeared on the front, and both tacticians and technicians at once recognised its possibilities. Under the stimulus of the demand for this new arm, its development was rapid. Starting with the crude observation plane of limited speed and radius of action, incapable of combat, we see the development of the larger plane capable of carrying bombs, and, before long, the fighting or pursuit plane adapted to aerial combat. With the advent of high powered and much faster machines, and more especially with the introduction of aerial combat, the training requirements rise far beyond those of pre-war days. The military pilot must be qualified to execute manœuvres which but a short time before had been considered possible for only a few outstanding experts. He must be capable of diving at high speed, of executing tight spins, reversements, and various other manœuvres which enable him to place his adversary at a disadvantage, or to escape when caught himself in an unfavourable situation.

III. Selection of Pilot Material

"Anyone can learn to pilot an airplane" is a popular saying. Yes, and anyone can learn to drive an automobile, but how many thousands are killed every year in auto accidents because of the drivers' lack of judgment or lack of facility in handling the steering wheel and brakes at a critical moment? Requirements for an auto driver's licence are in general not difficult, and perhaps rightfully so. The automobile is a recognised utility and convenience, the use of which cannot justly be denied the great mass of people capable of owning one. The same may be said of the private airplane owner, but we should not lose sight of the fact that it is easier for the unskilled incompetent airplane

pilot to cause a serious if not fatal accident—fatal not only to himself but to others. Piloting an airplane in three dimensions is admittedly more difficult than driving an automobile in two.

Just what limitations should be put on granting a private pilot's licence I shall not attempt to define, but let us hope that they may be more strict than those usually placed on granting an auto driver's licence. Statistics show, for instance, that airplane accidents are more numerous both among students and among licensed pilots who have been granted waivers on physical defects in issuing the licence than among the physically normal. Analysing the causes of accidents in miscellaneous flying in the United States over a period of six months, we find that more than half of these accidents are to be attributed to errors of the pilot, largely his poor technique.

A separate study of accidents in the case of licensed private pilots shows that over 16 per cent. showed physical defects which were waived in granting the licence, and this group contributed $33\frac{1}{3}$ per cent. more than its share of all accidents. Therefore we may expect more accidents if we grant pilot's licences to those showing physical defects, such as impaired vision, inability to judge distance or abnormal nervous condition.

Now, let me touch on the selection of pilots other than those classified as private. Under favourable conditions of weather, terrain, traffic and equipment, a mediocre pilot may go on indefinitely with no untoward event, no accident of consequence; but let an emergency arise, requiring quick and accurate thinking and correct use of the controls, and the mediocre pilot is likely to fail while the good pilot responds unconsciously by doing the right thing at the right time—which simply means that he has "inherent flying ability," and no one should be rated as a transport or military pilot who is lacking in this quality.

But you ask, "Who has this inherent flying ability, and how are we to determine whether or not it is present?" My answer is, first, that training alone will show positively its presence or absence, but preliminary tests may be given the candidate pilot which will give a clear indication of its absence. An example is the neuro-psychic examination in which the Flight Surgeon questions the candidate at length on his family history, on diseases his parents and he himself may have had; on injuries he may have suffered; on his likes and dislikes, on his habits, endeavouring to learn his characteristics; whether he shows indications of being an introvert or an extrovert; whether he is of the athletic type or not; the sports he has engaged in and any in which he may have excelled. This examination may bring out characteristics of mental instability which is a marked indication of the absence of inherent flying ability. The reaction test on a device which records graphically the length of time the candidate requires to respond to an aural or visual signal is another indication. In this test the examiner sits on one side of a board equipped with a series of lights and a buzzer; the student sits on the opposite side of the board. The examiner flashes on one or more lights—the candidate must move a switch to extinguish them; the examiner starts a buzzer—the candidate must stop it. The length of time to react in each case is recorded graphically on an instrument similar to the barograph, breaks in the line showing the length of time between the flashing on and flashing off of the lights, or the starting and stopping of the buzzer. Another device for this test consists of a pilot's seat with stick and rudder bar and a vertical and horizontal series of lights. By giving full left rudder, the entire line of lights to the left is flashed on and the candidate endeavours to give the correct amount of right rudder to extinguish them. If he gives too little rudder, some of the lights will remain on; if he gives too much, the lights to the right will flash on.

Another and very interesting machine, known as the orientator or flight tutor, gives a fair indication. This is nothing more than the cockpit of an airplane, with a propeller on the front and capable of being put through the ordinary

manœuvres, such as turns, banks, rolls and loops. The candidate is strapped to his seat, and with the standard stick and rudder bar is required to carry out various simple manœuvres; then, after a certain amount of practice, he is required to extricate himself from unusual positions in which he has been placed by the instructor, who operates a duplicate set of controls from the ground. Too much must not be expected of the candidate in the beginning of this test—it must be given gradually and he must have a fair opportunity to learn the effects of the controls. But by properly regulating the demands in accordance with his limited knowledge, it is possible within limits to discover the absence of inherent flying ability. The candidate who shows marked roughness in handling the stick and rudder, who becomes readily confused, who uses one control when he should use the other, and who uses a given control improperly, will generally prove to be lacking in inherent flying ability.

To be of value, these tests must be given by qualified personnel, trained in the subject and familiar with the object to be attained. Hurried, cursory tests will not bring out the qualities, or lack of qualities, sought.

Inherent flying ability is just what the term indicates, that is "inherent," and it is difficult to predict off-hand just who has it. All boys do not make good baseball players or cricket players, and similarly all boys do not make good airplane pilots. Some take to it naturally, and others never would make good pilots even after a prolonged period of training.

IV. Selection of Training Equipment

Choice of training equipment is controversial, and no doubt will long continue to be so, opinion varying from the adoption of an all-through, all-purpose training plane to a series of planes with varying characteristics, including the primary, intermediate, advanced and service types. The object of training varies, depending on the type or types of plane the student will eventually be called upon to fly, so naturally the training plane or planes which will fulfil the requirements for the private flyer will not fill those for the transport or military pilot.

You might say: "Why not train the student on the type of plane he will use?" But that would be prohibitive, both from an economical and an efficiency standpoint. The beginner requires a comparatively light, not too sensitive, easily-controlled plane, easy to take-off and especially easy to land, strong enough to stand the punishment of hard landings, and easy to get out of unusual positions and manœuvres such as stalls or spins. Limiting the number of different types of training planes has the great advantage of reducing maintenance and therefore cost, with the disadvantage of requiring the student at different stages of his training to perform manœuvres to which the plane is not especially adapted.

Aircraft design has advanced to the point where we can now have a training plane which is relatively easy for the beginner to handle, with a relatively slow landing speed of approximately 40 m.p.h., relatively stable, easily manœuvrable, positive on the controls, rugged in construction and therefore capable of standing hard landing and aerobatics, with sufficient horse-power to give the requisite speed and climb, and, at the same time, not over-powered to the point where the student can rely on the power of his engine rather than on the proper feel of the controls. This plane may well serve all purposes up to the point of putting the student on the transport or service type plane which he is eventually to fly.

V. Instruments

Until ready to go to the last type, instruments need not be numerous—a tachometer, an altimeter, and an airspeed indicator are a minimum, but they must be plainly visible.

In his early training, the student should not be hampered by trying to watch too many instruments; he should not have his eyes fixed on the instrument board but should be looking out for other planes in the air, should be watching the horizon to judge whether his plane is level, is climbing or descending. He should learn to recognise a slip or skid by the pressure of the wind on his cheek. A tachometer is essential, as no student can be expected to know without an instrument the speed at which his engine is turning. He takes off at full throttle, then, after reaching the desired altitude, should throttle down to the normal régime, which varies in different engines and on which he must be informed by the instructor. No student can be expected to correctly estimate his altitude, so an altimeter is essential. As a matter of safety, different students may be required to practise at different altitudes; the student may be required to land from a 180- or 360-degree turn, starting from a specified altitude which an instrument only can tell him.

An airspeed indicator is provided primarily as a means of safety. In manœuvring in the air, or in gliding to a landing, the student should refer to this instrument, especially in his early training, to avoid falling below a safe flying speed which might lead to a stall and loss of control with disastrous results.

A thermometer may be added to give warning of an overheated engine due to malfunctioning or to failure to adjust the shutters if the engine is liquid cooled.

VI. The Instructor

A good pilot is not necessarily a good instructor, any more than a good Greek scholar is necessarily a good professor, or a good football player a good coach, but the instructor must be a good pilot. Instructors vary from the exigent, over-critical, unduly hasty, abrupt, to the over-sympathetic, and perhaps it is just as well to have some variety in this respect, as students themselves vary from the over-confident to the timid. The best results are obtained by fitting the two together, and manifestly this does not mean assigning the timid student to the unsympathetic instructor. Even though an effort be made to adjust the student to the instructor, mistakes will be made, temperaments will clash, the instructor will fail to secure the best efforts or rather to develop fully the qualifications of a student, in which case a reassignment should be made at the suggestion of either the student or of the instructor, and both should feel free to make the suggestion.

The duty of the flying instructor is not easy, and the number of years he is on this study should be limited, his capacity in this respect varying with his physical and mental make-up; but it should be remembered that his value as an instructor increases materially with his experience. The new instructor, even though he be a good pilot himself, must learn to know what faults to look for in his students, and must acquire a standard by which to judge them. At first he will readily establish an opinion as to the relative ability of his own students, then if an older instructor of wider experience rides with them, his broader viewpoint and experience will assist the new instructor in determining the real standard attained by those whom he is instructing.

To obtain the best results, to develop the full ability of the student, the instructor must be a good pilot, must have patience, should be a psychologist to a certain degree, must be mentally adjustable and should have a firm determination to make a first-class pilot out of every student he instructs.

VII. The Object of Training

Pilots may be divided into three classes:—

(1) The private pilot.
(2) The commercial pilot.
(3) The military pilot.

Necessarily, the requirements of training for these three classes vary materially. In the case of the private pilot, the object is to bring him to a state of efficiency that enables him to handle his plane in the air and on the ground so as not to unreasonably endanger himself and especially not endanger others—spectators on the ground, passengers in his plane, or other planes in the air. The latter requirement is the most important. The private pilot must be entirely familiar with traffic rules, since the greatest danger lies in the vicinity of the aerodrome—in taking off and especially in landing. The private pilot differs materially from the commercial and military in that he can select his own time and weather for flying, and it is to be assumed that, as a matter of self-preservation, he will not take the chances that the commercial and military pilots must take.

The Aeronautics Branch of the U.S. Department of Commerce considers that a private pilot should be able to fly safely and competently as an amateur, and with this in view it requires him to have 50 hours of solo flying of which at least five hours must have been within the preceding 60 days prior to the filing of the application. The applicant is examined on air commerce regulations, including air traffic rules. Physically he must be free of any organic disease or defect which would interfere with safe handling of an airplane under the conditions of private flying, must have reasonably good eyesight and no organic disease of the eye or internal ear. In the practical flight test, he must make three satisfactory landings to a full stop; a series of three gentle and three moderately steep figure-eight turns; spiral in one direction from 2,000 ft. with engine throttled, landing in normal landing attitude by wheels touching the ground in front of and within 500 ft. of a line designated by the examiner.

A solo pilot's licence may be granted to all fulfilling the above requirements except they need have only ten hours of solo flying, at least two of which must have been within the preceding 60 days. The solo pilot is not permitted to carry passengers, while the regular private pilot's licence grants authority to carry passengers, but not for hire.

The commercial pilot, whether he carries passengers, mail, express or freight, is always faced with the responsibility of maintaining his schedule, and many accidents are traceable to the unwillingness of the commercial pilot to stop when he knows weather conditions are unfavourable. As a matter of fact, there is such a fine dividing line between " getting through " and " not getting through," and he goes through so often when conditions appear unfavourable that he is always tempted to continue and make the effort at times when discretion would dictate his staying on the ground or landing. With the great increase in facilities, such as regular and frequent weather reports, radio beacons, radio communications, airway lighting, emergency landing fields, the commercial airplane pilot's problems have been much simplified, and with his increased knowledge of flying and navigation, he can maintain a schedule to-day under conditions that were considered absolutely prohibitive a short time ago—not only maintain his schedule, but do so with fewer accidents and fewer casualties.

Increased restrictions on the pilot, such as requiring him to operate only with a reasonable ceiling and reasonable visibility have served to further decrease the number of accidents in commercial aviation.

The Aeronautics Branch of the U.S. Department of Commerce divides commercial pilots into three classes—limited commercial, transport, and scheduled air transport. They must undergo a physical examination which is more severe than in the case of the private pilot and relates particularly to the lungs, heart, gastro-intestinal, neuro-psychiatric, and genito-urinary systems. They must be free from material structural defects or limitations, free from disease of the ductless glands, must have normal vision, normal judgment of distance and equilibrium.

Limited commercial pilots are permitted to carry passengers for hire within the areas mentioned in their licences, usually within ten miles of a designated airport. They are required to have the same flying experience as private pilots, that is 50 hours solo flying of which five hours must have been within the preceding 60 days prior to the filing of the application. They are examined on air traffic rules and those portions of the air commerce regulations pertaining to pilots' privileges and limitations and to the inspection and operation of aircraft. They are given a practical and theoretical examination in elementary engine and 'plane mechanics and rigging. The practical flight test includes: normal take-offs and landings; from 1,500 ft. with engine throttled, a 360° turn, followed by a landing in normal landing attitude, with wheels touching ground in front of and within 200 ft. of a line designated by the examiner; from 1,000 ft. with engine throttled, a 180° turn followed by a landing in normal landing attitude, with wheels touching the ground in front of and within 200 ft. of a line designated by the examiner; a series of three gentle and three steep figure-eight turns, and 720° steep power turns in both directions; a spiral in one direction from 2,000 ft. with engine throttled and landing in normal landing attitude with wheels touching ground in front of and within 200 ft. of a line designated by the examiner; emergency manœuvres, such as spins, spirals, side-slips, climbing turns and recovery from stalls, and such others as may be deemed necessary.

Transport pilots have the same requirements as limited commercial pilots, but in addition undergo a theoretical examination in the fundamentals of meteorology and air navigation, and in the practical flight test are required to make a flight over a triangular or rectangular course at least 100 miles in length, ended by a landing at the place of take-off within five hours from the beginning of the flight. This flight shall include two obligatory landings not at point of departure, when craft must come to rest.

To pilot aircraft carrying passengers for hire at night, that is, between half-an-hour after sunset and half-an-hour before sunrise, a transport or limited commercial pilot must have had at least two hours of night solo flying within the last preceding 90 days; at least three of his landings must have been to a full stop.

Recognising the necessity for further safeguarding the lives of passengers on regular air transport lines, many of which now operate through the night, the Department of Commerce has prescribed what is called a Scheduled Air Transport Rating, applicable to pilots flying airplanes engaged in scheduled operation of inter-state air transport service. These pilots must have had 1,200 hours of certified solo time within the last eight years, of which at least 500 hours have been cross-country, and 75 solo hours of night flying of which at least 50 per cent. shall have been cross-country over lighted airways. The examination includes a practical and a theoretical test on the use of directional radio and other available airways aids to navigation, including tests in meteorology with respect to weather analysis and forecasting. Practical flight tests are given in a hooded cockpit, under the conditions of instrument flying, performing the following manœuvres with recovery to a predetermined heading:—

(*a*) Straight level flight.
(*b*) Moderate banks making 180° and 360° turns in both directions.
(*c*) Minimum glides and maximum climbs and approaches to stalled attitudes of flight.
(*d*) Climbing turns.
(*e*) Recovery from stalls, skids, slips, spirals and banks in excess of 45°.

As for the military pilot, candidates for training in the Army Air Corps training centre must be unmarried male citizens of the United States, between the ages of 20 and 28, who shall have satisfactorily completed at least two years of college work or shall be able to pass an examination which is the

equivalent thereof, shall be of sound physique and in excellent health. The course covers such ground school subjects as meteorology, airplanes, engines, navigation, radio, aerial gunnery, and other subjects necessary to the military pilot. He is given approximately 265 hours in the air, on the completion of which he is commissioned as a second lieutenant in the Air Corps Reserve and receives his army pilot rating. Usually graduates are sent to squadrons for one or two years of active duty, provided funds are available for this purpose.

The U.S. Navy gives a course of training for the naval reserve quite similar to that of the Army Air Corps, with the exception that candidates are received at 18 years of age and the training course lasts only nine months. The first month is elimination training, and upon the successful completion of this, the students are sent for eight months' additional training at the regular naval flying school. The graduates may be selected for one year's active duty with the fleet air squadrons, and are expected to serve 15 days on active duty each year, to maintain their efficiency as pilots.

As noted before, a pilot must have two qualifications which are quite different, but both essential to the good pilot. He must acquire technique—by which I mean the ability to handle his controls smoothly and logically—but, in addition, he must have good judgment, and these qualities are not always found together. Many students acquire technique—that is, skill, dexterity and co-ordination of the senses in handling the controls—but, faced with an emergency, they may utterly fail in the very essential requisite of good judgment. The instructor may give the student a very simple test by suddenly throttling or cutting the motor at an unexpected moment and requiring the student to make an emergency landing. With proper training, the student who has the necessary judgment will select the best available landing point within gliding distance, will follow the proper pattern in arriving at the field, will head into the wind and land without injury to himself or plane, whereas the student who is lacking in judgment may not only fail to select the proper field and perform the correct manœuvres for reaching it, but, under stress, may even fail to exercise the technique which, under normal conditions, he has previously demonstrated.

VIII. Instruction

The instructor starts with a familiar talk with his student, in order to learn his personal characteristics and temperament, to make him feel that he has a personal interest in him. He instructs him in nomenclature, in the use of equipment, in the action of the controls, sees that he is comfortable in the machine, that his parachute is properly fitted; reassures him as to the dangers of flying and endeavours to put him at his ease, stressing the necessity for keeping relaxed at all times in the air and for avoiding that feeling of tenseness so often experienced by the beginner, which causes him to grip the controls. As a matter of fact, this is a common fault found in all students in varying degrees—commonest perhaps to the older student, to the apprehensive student, and to any student in the beginning.

After preliminary instruction on the ground, the student is ready for flying training, at first limited to periods of approximately 20 minutes. Some of the remaining time may well be spent on the flying line, watching the other students at work, listening to advice and counsel which the instructor should give freely and frequently to all his students between periods in the air. A few minutes before and after flying—devoted to explaining what is expected of him, what mistakes he has made, how to avoid them, a little praise where due—will always encourage and assist the student.

If he has never been in the air give him a ride, avoiding aerobatics and endeavouring to inspire his confidence both in the machine and in himself. Again impress on him the necessity for being relaxed, sitting easily, and avoiding

gripping. Let him place his hand and feet on the controls and follow lightly as you move first one and then the other. In his first lessons, show him the effects of controls " stick to the left—the left wing goes down; stick to the right—the right wing goes down," etc. As he progesses, demonstrate and have him execute the elementary manœuvres such as normal glides, flat and steep glides, gentle turns and turns in glide, followed by gentle and steep eights; and, when he has acquired a feel of the machine, pass to landings and take-offs. Taxying, climbing turns, stalls, spins, steep banks, forward- and side-slips, and steep landings follow in turn.

After six to ten hours of dual instruction, a young student (say 28 years of age or less) should be ready for his first solo, and if he is not it is an indication of something abnormal. It may be a clear case of lack of inherent flying ability, in which case—if he is training for a military or transport pilot's licence—he should be advised to choose some other career, both for his own good and for the good of those for whose safety he might later be responsible. He may be a " slow student," that is one who does not learn quickly but absorbs well what he does learn. It may be that his slowness is due to some outside influence which, on investigation, can be determined. His physical or mental condition may temporarily unfit him for flying training. Here is where the Flight Surgeon's knowledge should be utilised. A Flight Surgeon trained in neuro-psychology, living in close touch with the student, observing him at work daily, is often able to detect, even before the student himself, a condition—physical or mental—such that if the student continues, he not only may not do justice to himself, may be a failure as a student, but may, of course, make one of those mistakes which lead to serious accidents. The Flight Surgeon should always be ready to detect these conditions and advise the suspension of training of any student who is considered temporarily unfit to continue.

I have set six to ten hours as the normal requirement of dual instruction to qualify the *young* student for his first solo flight. An older student will as a rule require longer, in fact the length of time devoted to preliminary dual instruction is a function of age as well as natural ability. The older student is invariably more tense, has less elasticity of mind, less ability to co-ordinate, and can never expect to reach the high standard attainable by the man who starts his training when he still possesses these qualities.

It is popularly supposed that the very young man makes the best flyer, and undoubtedly in time of war the energy and enthusiasm of youth are important factors in the make-up of the military pilot, but experience shows where a high standard of efficiency is demanded, the ones most likely to meet this standard are between the ages of 24 and 26. It is reasonable to suppose that the average young man of this age still retains his adaptability and in addition has acquired a certain amount of judgment which may be lacking in the younger man of 20 to 23.

Early in his dual instruction period, the instructor should give the student the experience of stalls, loops and especially spins, to show him the ease of recovery from unusual positions and thus increase his confidence both in himself and the machine.

His solo practice at first should consist simply of taking off, circling the field and landing, repeated until he has acquired confidence; then he repeats the manœuvres previously enumerated, and I cannot stress too strongly the importance of interspersing his solo practice with frequent returns to dual instruction.

Forced landings, cross-wind take-offs and landings, landings to a mark from straight glides, from 180° and 360° turns with motor throttled, figures of eight, landing over an obstacle, cross-country flying, all have their place in instruction and lead up to the advanced training in aerobatics which is not essential for the

private pilot, but indispensable to the military pilot and highly desirable for the commercial pilot.

Aerial navigation is another requirement which is insisted on in the case of the commercial and the military pilot, and this dictates a certain amount of cross-country training. An " aerodrome pilot " is of little value in these days, and the experience of the last war thoroughly demonstrated the necessity of cross-country training. I can recall many occasions in which pilots started for a given destination and arrived at an entirely different one, often in a direction quite contrary to the one they were supposed to take.

Concurrent with this flying instruction, the student should be devoting the extra hours to ground instruction, both theoretical and practical, in the subjects closely related to flying, including nomenclature, flying regulations, aviation engines; airplanes, including construction, rigging, maintenance and repair, instruments; meteorology and aerial navigation.

I would again stress the necessity for frequent return to dual instruction, as it will save time in the end and will prevent the student from acquiring bad habits which, if not checked in the beginning, may seriously interfere with the progress of his training and even prevent his continuing it to a successful completion. Another useful means at this stage, and at later stages of training, is to let the student go back to the Flight Tutor or Orientator and work out for himself difficulties which the instructor has noted. It may help him in smoothing out his handling of the controls, especially if he is having trouble in executing some particular manœuvre. It is a fact demonstrated by experience that there is a material saving of time in adopting this method of occasional periods on the Flight Tutor.

IX. All-through or Stage System

Another controversial question is whether the all-through or stage system is the better. By " all-through " I mean the system in which the student is carried by the same instructor through the various stages of his instruction, and by " stage " I mean progressing from one stage to another, each stage under a different instructor. I am convinced that a combination of the two systems brings the best results, and while the student should have the benefit of flying with the same instructor through the earlier period of his training, it is of assistance to him later to pass to different instructors; and even in the primary stage it is advantageous to fly with an older and more experienced instructor from time to time who can check up on his peculiarities. Instructors have their personal equations, and even when trained under the same system are likely to vary somewhat in the method of imparting knowledge to the student. One instructor will stress one manœuvre, another instructor a different one. No rider is expected to become adept who has all his training on one horse; he should have the experience of riding a variety of horses with different characteristics, different peculiarities, and similarly the student-pilot should have the benefit of training under a variety of instructors and of flying different types of planes.

X. Instrument Flying

I would stress blind or instrument flying as another absolutely necessary requirement for commercial and military pilots, and cloud or fog flying is now relatively a simple matter for those who have had this training. The day has passed when a pilot can claim he is able to fly entirely " by instinct," instead of by instruments. This was not readily accepted in the beginning by many of the older pilots, who insisted they could fly by " feel " with no visibility. However, a very simple device can prove to them their error. By placing the student in a revolving chair with his eyes blindfolded, then turning him first in one direction, then in another, reversing, stopping, turning again, it will be seen

by his reactions that he is unable to determine the direction in which he is turning, or even whether he is turning at all. Similarly, in the application of this to actual fog flying, a pilot may be under the impression that he is turning left when he is turning right, or may fail to recognise a change in the attitude of the machine—and even if he correctly determines what the plane is doing, his tendency is to over-control when correcting. For that reason, it is imperative that he should learn to rely implicitly on his instruments and not on his sense of feel when flying blind. Simple instruments are now available, based on the principle of furnishing an artificial horizon when the real horizon is not visible. A common form is one in which the pilot has before him on the instrument board a miniature airplane which appears to assume the attitude actually assumed by

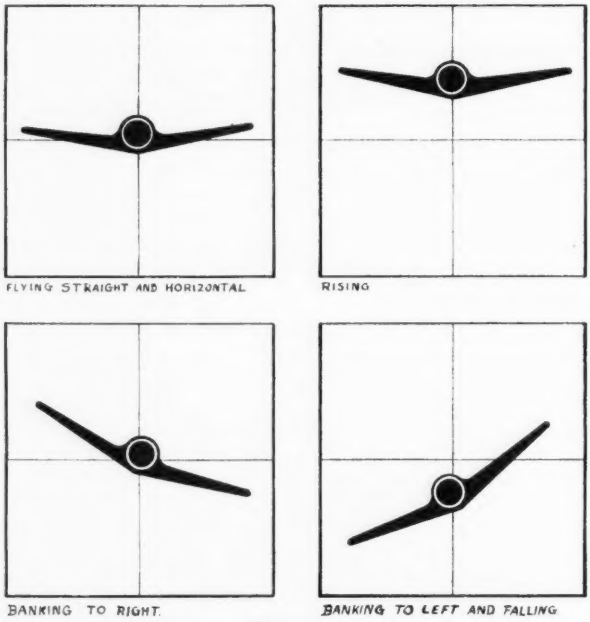

FIG. 3.

Miniature acroplane on instrument board showing attitude of actual acroplane.

the plane. The pilot has simply to operate his controls in such a way as to keep the miniature plane in the attitude he wishes to assume. For instance, if the left wing of the miniature plane is down, he knows he is flying with the left wing low, and has only to move the stick to the right until the miniature plane assumes a horizontal position, when he knows he has raised his left wing and has regained his lateral balance. Eight to ten hours' instruction in instrument flying is the average amount required to teach a pilot to fly with no other assistance than that provided by instruments.

XI. Experience in Traffic

Another essential in the training of all pilots is experience in traffic. Some students are habitually unobserving and fail to take into account the necessity for watching for other planes in the air. Early in his training the student must

be taught to be on the alert, particularly in the take-off, and even more so in approaching for a landing.

XII. The Mechanical Flyer

A type of pilot or student which we sometimes encounter is the mechanical one, by which I mean the one who flies by rule of thumb or by reference to his instruments rather than by his feel of the controls and of the plane. There should be no confusion between this mechanical pilot and the one who flies by instruments when flying blind. The latter applies to flying in a fog, that is with no visibility, in which the pilot must learn to rely on his instruments and not on his sense of feel. For instance, a heavily-loaded plane flying in a fog may turn, slip, climb or glide, and eventually fall into a spin. The pilot should rely on his instruments and not on his sense of feel to hold the plane straight and level as his sense of feel cannot be relied upon 100 per cent. On the other hand, in normal flying, the student must not depend on his instruments or mechanical means to tell him whether he is flying straight and level or is performing a manœuvre properly. It is all very well to tell the student to keep the radiator cap on the horizon in straight and level flight, to take off a certain amount of rudder after banking for a turn, but he must acquire the facility of doing this automatically, of using the right amount of aileron and rudder in the turn, the correct combination of the controls for executing the manœuvre without slip or skid. By " mechanical flying " I refer to the one who mechanically executes the manœuvre according to the rule laid down, but fails to properly combine the use of the exact amount of each control at exactly the right time. Failure to do so indicates a lack of feel which is characteristic of the mechanical pilot, and this type can never acquire the high degree of skill requisite in a first-class flyer.

XIII. Reaching a Peak

Another peculiarity found in some students is what is termed " reaching a peak." Many students will advance normally in their training to a certain point and then their progress stops. This may occur in transferring from one type of plane to another; for instance, from a training type to a service type, and while the student may prove entirely satisfactory up to his peak, his further progress may prove quite unsatisfactory.

I would say in this case that you can distinguish between the private and the commercial and military pilot, for many students will reach a point where they might be entirely satisfactory as private pilots, but could never reach the degree of efficiency required of a commercial or military pilot.

And even after a student has completed his regular course in the flying school, he should not make the mistake of considering himself a first-class pilot as he still requires the training of experience which can only be acquired by many hours in the air under varying conditions of weather and traffic. Only the pilot who has been faced with emergencies and learned to meet them can be rated as first-class.

XIV. Over-confident Period

There comes a time in the course of his training when the average student becomes over-confident. After passing through the various stages, and in particular through aerobatics, that is after 75 to 100 hours in the air, he reaches the point where he feels he is complete master of his plane and can do anything he chooses with it. This is a critical stage and the one in which serious accidents are most likely to occur. A loop too near the ground, recovery from a spin when it is too late, a manœuvre for which the plane is not constructed, and he

oversteps the narrow line of demarcation between success and failure, between completing the manœuvre as planned and—a fatal crash. Many students and young pilots pay the penalty for over-confidence, while others are fortunate enough to survive and come out having learned a valuable lesson which serves them in good stead throughout the remainder of their flying career.

XV. Air Transportation To-day

Before looking into the future use of aircraft and its influence on the training of pilots, let us consider the present state of development, particularly the restrictions and facilities in aerial transportation.

In the United States scheduled air transport pilots are required to establish their ability to handle their planes efficiently at night and in fog or clouds when there is no visibility. They may carry passengers for hire only in licensed aircraft of the types and classes specified in their pilots' licences. They must be thoroughly familiar with the route flown. They may not fly at less than 500 feet altitude unless: there is definite indication of favourable or improving weather conditions ahead; there is sufficient ceiling to permit safe manœuvring of the airplane without striking the ground and visibility of at least two miles in daylight, or from beacon light to beacon light at night; directional radio is in operation and the plane is equipped for receiving its signals, also weather reports, when flying at night; the pilot believes he can accomplish the flight with safety. Air transport planes must be pronounced airworthy by the Department of Commerce. If operating in daylight, they must have a complete set of instruments including duplicate turn and bank indicators, compass, air speed indicator, climb indicator, sensitive type altimeter adjustable for changes in barometric pressure, thermometer, clock or watch, complete set of engine instruments, fire extinguisher, first-aid kits, suitable ash containers where smoking is permitted, maps covering an area of 75 miles on each side of and beyond the ends of the route showing airports, radio communication stations, radio beacons and intermediate landing fields. For night flying, additional requirements include: electric landing lights, navigation lights, cabin lights, instrument board lights, flash lights and safety belts or seats firmly secured in place. A reserve of 35 per cent. of fuel is required, over and above the amount necessary between scheduled stops. Radio apparatus must be provided for receiving radio range beacon signals and weather reports.

A co-pilot, holding a transport licence, is required on planes having a capacity of 15 passengers or more, on planes of 15,000 pounds or more gross weight, and where the pilot flies five or more hours in one day in aircraft having a capacity of eight passengers or more.

The Department of Commerce prescribes regulations relative to the maintenance of equipment, to airways and air navigation facilities, and to the operation of planes while flying the airways.

In connection with the above restrictions on scheduled air transportation, let me describe some of the facilities provided by the Department of Commerce. The main airways are provided with approximately 90 radio range beacons, each having an effective range of about 100 miles. These are supplemented by some 80 radio marker beacons which serve to mark strategic points along the airways such as mountains or other obstructions, and junction points of adjacent radio range beacon courses. They are equipped with two-way radio phones for communicating with passing aircraft, and the newer ones operate as miniature radio range beacons so that in case of bad weather the pilot can follow the beacon to the intermediate landing field on which it is located.

The Department of Commerce provides about 20,000 miles of lighted airways marked by rotating beacons 10 to 15 miles apart which guide the pilot when visibility permits. These beacons are of one million candle power or more and

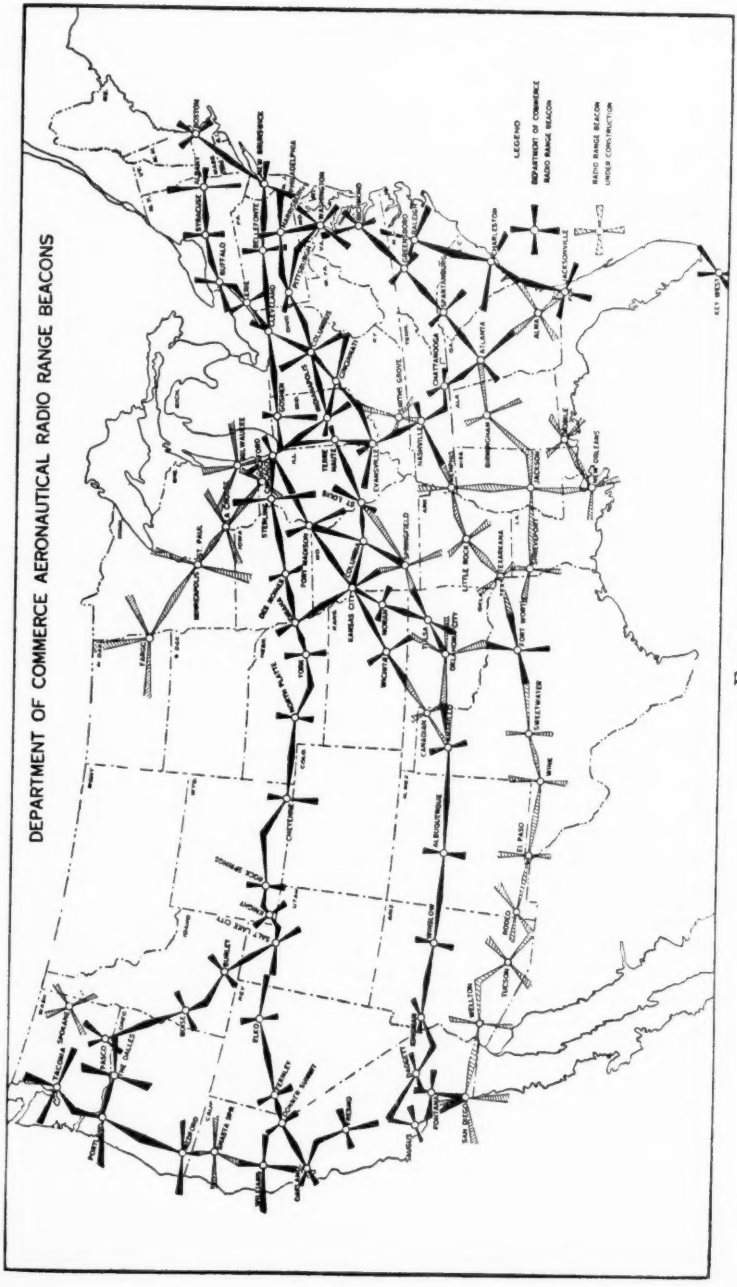
DEPARTMENT OF COMMERCE AERONAUTICAL RADIO RANGE BEACONS
LEGEND
DEPARTMENT OF COMMERCE RADIO RANGE BEACON
RADIO RANGE BEACON UNDER CONSTRUCTION

FIG. 4.
Department of Commerce Aeronautical radio range beacons.

show six flashes per minute. With them are red or green course lights which flash a signal indicating just which beacon in the series the pilot sees. When he comes to a beacon showing a green course light instead of red, he finds an intermediate landing field, the perimeter of which is marked by boundary lights three hundred feet apart. These intermediate fields are located at about 50 mile intervals.

The Weather Bureau collects meteorological data both at stations on the airways and at stations about 200 miles on both sides. This information is broadcast hourly over the airways, so is available to the pilot both before leaving an airport and while in the air. A new development in teletypewriter transmission now enables the Department of Commerce to transmit, six times daily, a weather map with symbols showing ceiling, visibility, temperature, wind direction and velocity and general conditions such as clouds, rain and snow, at all reporting stations, together with barometric pressures from which the receiving stations fill in the isobars, thus showing the centres of high and low pressure.

The teletypewriter has greatly improved the communication system in airways and the 250 stations now equipped with these machines are constantly receiving reports of the movement of planes over the airway and weather reports. Some 70 of these machines are equipped for weather map transmission and reception as noted above. The operator at the sending station places a blank copy of the map in the teletypewriter, then registers the characters on his machine by operating the keyboard as on a typewriter. This registers at the receiving stations on blank maps which have been placed in the teletype receiver.

Successful experiments have been carried out with radio landing beacons, and while they are not in use to-day it is safe to say that it is only a question of time until they will enable the pilot to land his plane on a field entirely covered with fog. The system is based on four separate elements: first, a runway localising beacon situated on one side of the field and just off the airport, which serves to guide the pilot in the proper vertical plane for approaching the field; second, adjacent to the runway localising beacon station is a landing beam station which sends out a radio beam with 40° horizontal spread and inclined upward across the aerodrome; third and fourth, two marker beacons, one about 1,000 feet from the border of the field and the other directly on the border.

After following the ordinary radio beam to the vicinity of the field, the pilot orients his course on the runway localising beacon, then follows on the landing beam which guides him downward in a vertical plane, gradually losing altitude as he approaches the border of the field. He does not actually follow the axis of the landing beam as in this case the signals would become increasingly stronger as he approaches the landing beam station. What he does is to follow a curved course underneath the beam such that its signal strength is constant as indicated by a pointer on his receiving instrument. About 1,000 feet before reaching the edge of the field, a buzz in the earphone tells him he is passing over the first marker beacon, and just as he reaches the edge of the field a different sounding buzz tells him he has reached the landing area. He then throttles his engine and using the landing beam as a guide makes contact with the ground. A relatively simple instrument on the plane furnishes the pilot with the necessary information relative to the runway localising beacon and the landing beam. If his course is to the left of the runway localising beacon, a vertical pointer moves to the left on his instrument, and similarly if he is to the right of the runway localising beacon. On the same instrument is a horizontal pointer which moves upward if his course is too high on the landing beam, and downward if he is too far below it. Thus the pilot has only to keep the vertical and horizontal pointers in the middle of his instrument to keep the plane on the proper course and at the proper altitude.

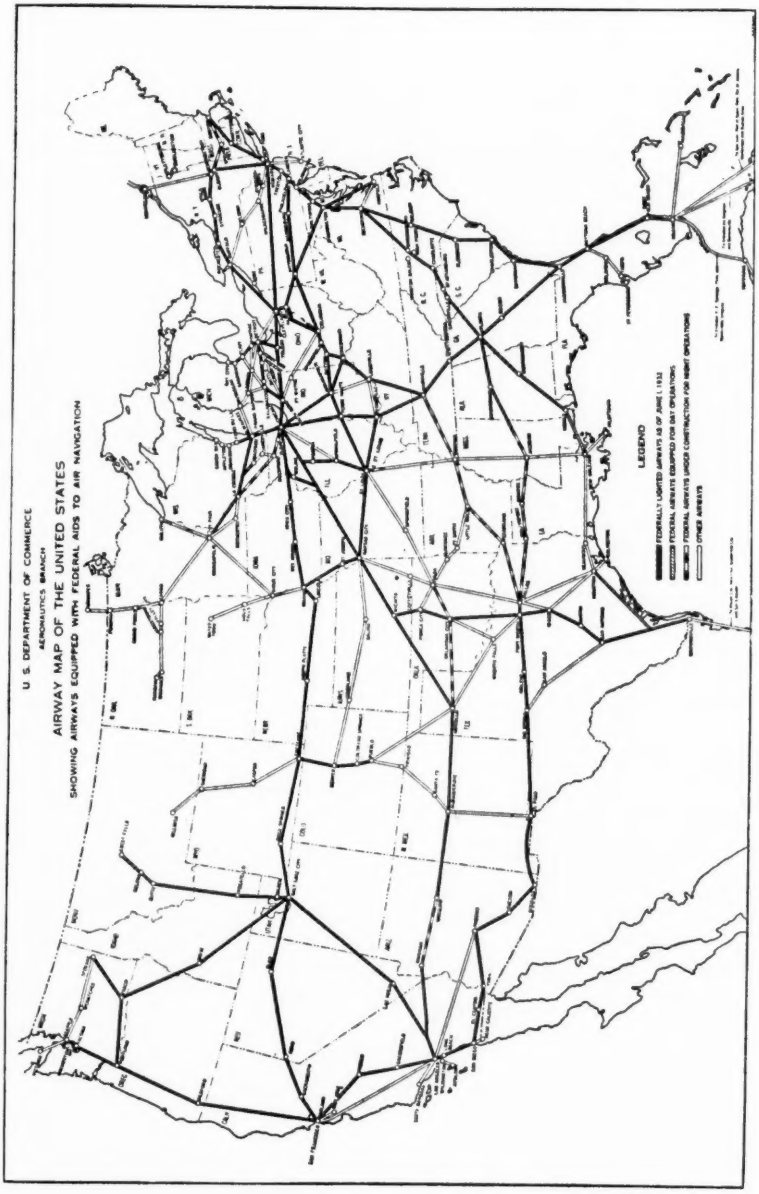
U. S. DEPARTMENT OF COMMERCE
AERONAUTICS BRANCH
AIRWAY MAP OF THE UNITED STATES
SHOWING AIRWAYS EQUIPPED WITH FEDERAL AIDS TO AIR NAVIGATION
LEGEND

FIG. 5.
Airways equipped with Federal aids to air navigation.

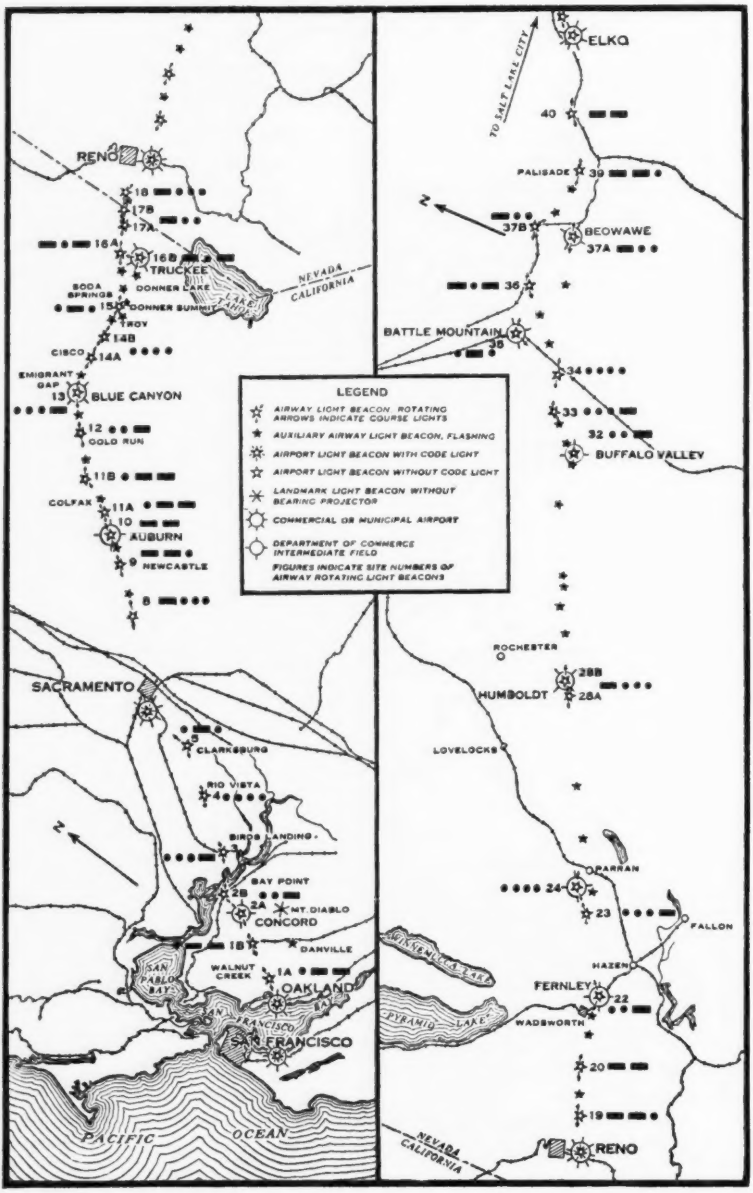

FIG. 6.
San Francisco—Salt Lake City Airways.

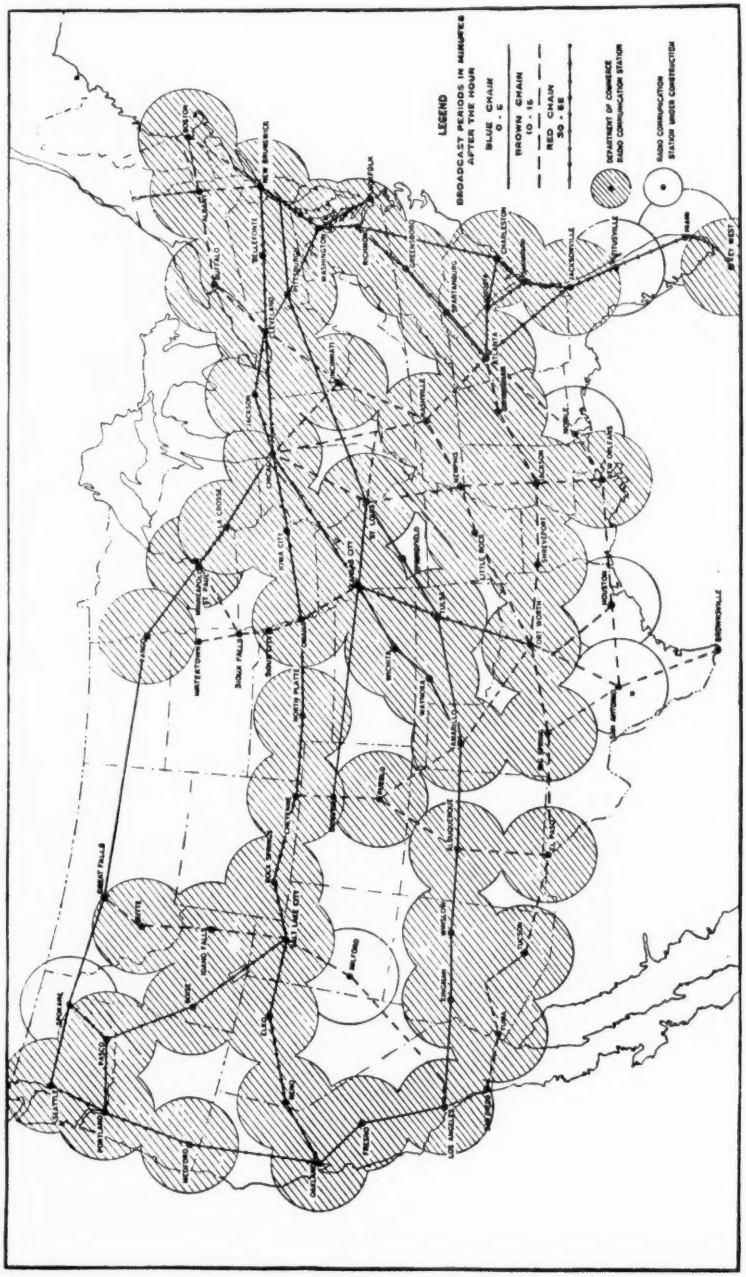

FIG. 7.

Chain assignments of airways communication stations.

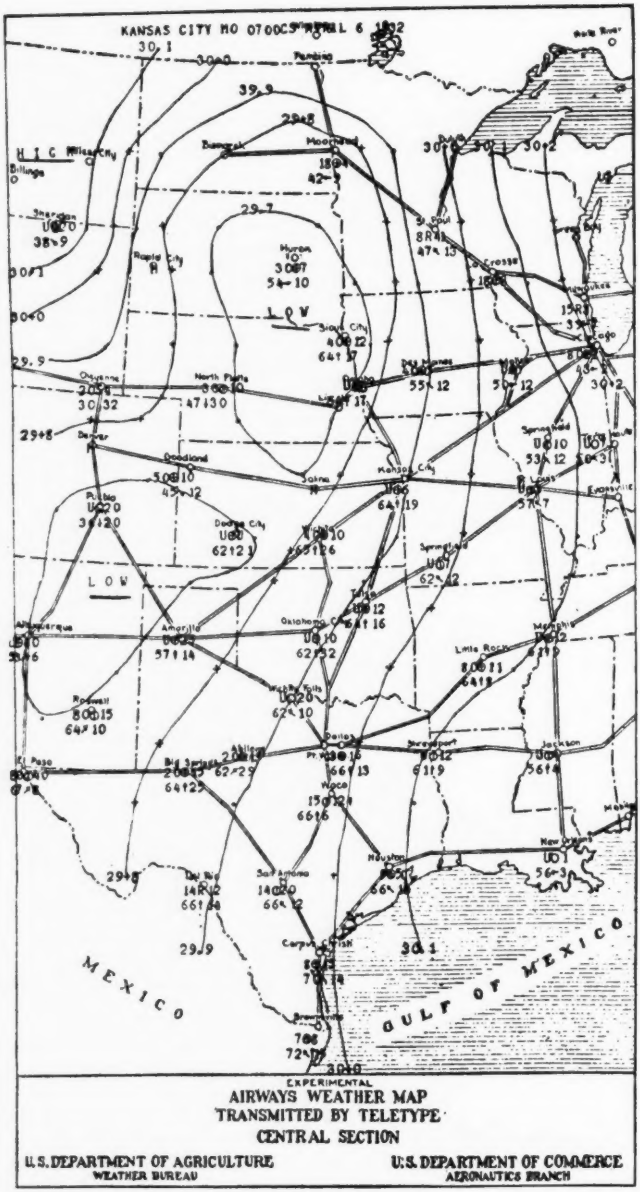

FIG. 8.

Airways weather map transmitted by teletype.

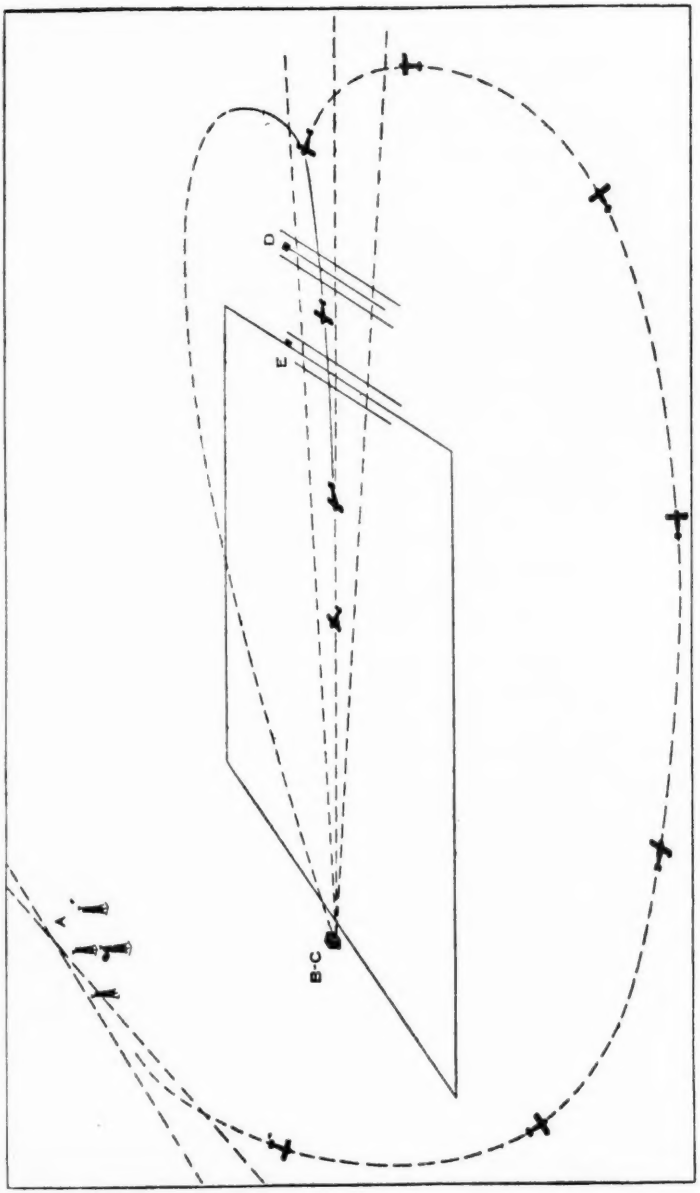

FIG. 9.

Diagram of airplane landing by means of radio system for blind landing. A indicates location of main radio range beacon; B and C, the runway localising beacon and landing beam; and D and E the marker beacons.

Numerous other aids are furnished the cross-country pilot, such as markings on the roofs of buildings and on the highways, obstruction lights on obstacles, and auxiliary landing fields with characteristic markings provided by private enterprises.

Obviously the cross-country pilot has numerous facilities at his disposal, but it is equally obvious that he must know how to take advantage of them, and in the case of the transport pilot the Department of Commerce requires nim to have the requisite knowledge of his route, of its markings and symbols, of his maps and of the use of radio, all of which enters into his training as a pilot.

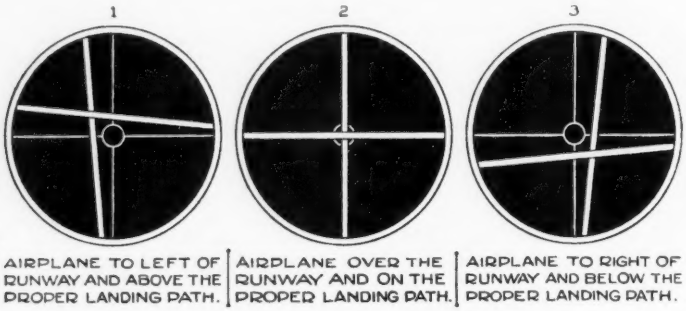
1
2
3
AIRPLANE TO LEFT OF RUNWAY AND ABOVE THE PROPER LANDING PATH.
AIRPLANE OVER THE RUNWAY AND ON THE PROPER LANDING PATH.
AIRPLANE TO RIGHT OF RUNWAY AND BELOW THE PROPER LANDING PATH.

FIG. 10.

The dial of the combined instrument with the needle pointers in three different positions.

Air Traffic Control

Recognising the necessity for safeguarding aircraft, especially in the air, the Department of Commerce issued a set of Federal Air Traffic Rules in 1928 which apply to all aircraft and airmen, military and civil, in both interstate and intrastate flying. These rules prescribe: that aircraft shall keep to the right side of established civil airways; that airplanes shall give way to airships and airships give way to balloons; that aircraft shall not in general come closer than 300 feet to other aircraft, this being considered a minimum safe distance; that in crossing courses, the aircraft which has the other on its right side, shall give way; that in approaching head on, they shall keep to the right; that overtaking aircraft shall keep clear of those overtaken; that except in taking-off and landing, aircraft shall not fly at less than 500 feet, nor over the congested parts of towns except at a height sufficient to permit of a reasonably safe emergency landing, which in no case shall be less than 1,000 feet; that no flight under 1,000 feet shall be made over any open-air assembly of persons, except with permission of the Secretary of Commerce; that aerobatics shall not be performed over the congested area of a town, over an open-air assembly of persons, or below 2,000 feet over a civil airway, or at any height over an established airport or landing field, or within 1,000 feet horizontally thereof; that any aerobatic manœuvres shall be concluded at a height greater than 1,500 feet; that aerobatics shall not be performed with any airplane carrying passengers for hire. The rules prohibit the dropping of any object which may endanger life or injure property except when necessary for the personal safety of the pilot, passengers or crew. They prohibit the transportation of explosives without the permission of the Secretary of Commerce, except for signalling purposes and fuel.

Take-offs and landings must be made up wind when practicable; shall not be commenced until there is no risk of collision with landing aircraft or others

taking off; shall not be made from or on a public street or highway without the approval of both the local authorities and the Secretary of Commerce. When within 2,000 feet horizontally of the leeward side of the landing field, airplanes shall, if practicable, maintain a direct course toward the landing zone; landing planes have the right of way over those on the ground or taking-off and those landing from higher altitudes shall give way to those landing below them. An aircraft in distress has free way in attempting to land.

At night, that is between one-half hour after sunset and one-half hour before sunrise, airplanes in flight must show a green light on the right side and a red light on the left side, visible at least two miles; also a white light at the rear visible at least three miles. Airships and balloons in the air must be lighted at night; also when anchored on navigation lanes on the water. Balloon and airship mooring cables must be lighted at night with groups of three lights at intervals of at least every 100 feet. Streamers take the place of these lights in daytime.

Air traffic rules prescribe distress signals as follows:—

1. The international signal S.O.S. by radio.
2. The international code flag NC.
3. A square flag having either above or below it a ball, or anything resembling a ball.

When an aircraft is forced to land at night at a lighted airport, it must signal by making a series of short flashes with its navigation lights. In fog, mist, or heavy weather, an aircraft on the water in navigation lanes, when its engines are not running, must signal its presence by a sound device emitting a signal for about five seconds at two-minute intervals.

At the time the above air traffic rules were issued, the Department of Commerce was fully aware of the necessity for regulating air traffic at airports, the "bottle necks" of air transport. This may be viewed from the standpoint of promoting the safety of operations, of speeding up the movement of aircraft on to the landing area and through the port to a hangar or parking area and to the open airway again. A further consideration is the cost of airports. With a view of making a thorough study of the subject of traffic control at airports, a committee was formed with representatives from various agencies such as the Aeronautical Chamber of Commerce, American Engineering Council, National Advisory Committee for Aeronautics, the National Bureau of Standards, the Army Air Corps and the Bureau of Aeronautics of the Navy Department. Twenty-eight sub-committees were organised, the members of which were drawn from airport managers and engineers and air transport officials. A preliminary report was published in December of 1930 and completed recently by a final report which covers the matter as thoroughly as possible with the information available to date.

The Committee investigated its subject from the viewpoint of landing area design and general signalling requirements, including both aural and visual radio, flags, lights and panels. The report embodies a uniform set of field rules for airports, a description of air traffic control projectors, a description of typical smoke generators for wind indication and time studies of airport traffic flow at various airports.

Over two years ago the Committee's investigation showed that the movement of approximately 25 planes an hour represents an airport's capacity, but this was based on the case where only one plane can take-off or land at a time. Investigation further brought out the desirability of limiting flying on any one airport to special purposes; for instance, it is manifestly undesirable to have a flying school operating on the same field as transport airplanes. In some cases it is probably desirable to confine the activities of a given airport exclusively to the despatch of the latter.

We find various designs of airports, such as those in which a single movement landing area is provided, with runways in as many as eight different directions which is considered amply sufficient for any direction of wind. Another landing area design is one in which a number of sets of double runways or traffic lines are provided, one in each set being reserved for take-offs and one for landings. A third type is called the tandem landing area which is applicable particularly where there is a constant direction of wind and where long runways may be provided in the direction of the wind. In this case the leeward end is reserved for landings and the windward end for take-offs. Another is one in which landings are made to the right and take-offs to the left of fixed traffic axes.

A very important consideration in landing areas is the reduction of taxying required both before taking-off and after landing. In general this is met by requiring planes to follow a taxy runway on the border of the field to the taking-off place and to taxy from the landing point directly ahead to the taxy runway on the edge of the field.

Two fundamental methods of controlling traffic by signals are in use, one in which communication is made directly with each plane, and the other in which the system controls the flow of traffic but does not attempt to communicate with each individual. Evidently the latter must be applied where the traffic density prohibits the former.

Both radio and visual signals are now in use, regulated from a control tower. Operation of the radio system may be described as follows: When an approaching aircraft is from three to five miles from the airport, the control officer, who has been previously warned of its approach, calls the pilot, giving him information as to the condition of the landing area, wind direction and other planes in the vicinity. This communication is constant until the pilot actually starts to land. After the plane is on the ground, the pilot is warned as to the position of other planes on the ground, but particularly with reference to those coming in to land behind him. When a plane is ready to leave the aerodrome, the control tower calls the pilot and gives him all necessary information relative to direction and wind velocity, planes in the air and on the ground, and when to taxy out for the take-off. In the visual system, a series of green flashes from the control tower projector is the signal to take off, while a red light is the signal to stand by and wait for the completion of other plane movements.

Smoke generators installed in the centre of the landing area are now recognised as the best means of indicating both wind velocity and direction by day. So far as is known, no satisfactory means have as yet been developed for illuminating the smoke at night. Wind cones and wind tees are still in common use, and while not as efficient in daytime as smoke generators, they are found necessary at night as they can be suitably illuminated.

The Air Commerce Committee recommends that traffic axes be numbered consecutively in a clock-wise direction around the landing area, beginning with the first runway to the left of the control tower, and that these runways be marked with international orange or chrome-yellow numbers to facilitate directing the flow of traffic. For night operations, these markings should be illuminated with green lamps and so regulated that only one number can be illuminated at the time so as to designate to the pilot which particular runway he must use. The Committee further recommends that similar numbers not less than six feet in height be displayed from the control tower so that they may be seen from the hangar lines and from any point on the landing area for the purpose of indicating the traffic axis to be used.

XVI. The Future

When we abolish war, there will be no further need for military pilots. I will *not* set a date for the inauguration of this happy era, and, much as we

should all like to see it, for the present we shall continue to train pilots for service in war. With respect to present equipment we may expect refinements in details and an approach toward standardisation in training with the exchange of knowledge on the subject between authorities of different countries.

Already mechanical control has appeared on transport airplanes to lighten the burden of the pilot; improvements in navigational facilities, in instruments, in radio communication, in meteorological information, in radio beacons, in means for preventing the formation of ice on the plane, the provision of means for landing with little or no visibility, all these are simplifying the duties of the commercial pilot.

Aviation is but in its infancy, the airplane scarcely more than a quarter of a century old, and who can predict what the flying machine of the future will be? Manifestly it will be easier to operate than the 1933 model. Already we have indications in the autogiro, in wheel brakes, in slotted wings, flaps and various other devices giving a greater range of speed, that is a lower speed for a higher flying speed, a lower stalling speed, better and easier control on the ground and in landing. But to counterbalance the easier handling of the machine of the future, the pilot will be faced with greater responsibilities. With the advent of the cheaper and relatively fool-proof flying machine, we must foresee the day when it will be in the hands of the private owner in numbers comparable with those of the automobile of to-day, when he will fly under less favourable conditions of visibility. Control of traffic in the air will then be a real problem, one in which the lame, the halt and the blind, or even the partially blind, must be eliminated; one in which the irresponsible joy-rider must be barred and pilots' licences granted only to those who have the requisite knowledge of flying regulations and give a reasonable indication of being able and willing to observe them.

To-day we cross the Channel or the Mediterranean daily by air—to-morrow we will cross the oceans; to-day we fly in the atmosphere, rise above mountains ten to fifteen thousand feet high; to-morrow we will fly in the stratosphere, at 80,000 feet, perhaps higher.

Surely the type of pilot to meet these responsibilities must be at least as good as the one of to-day and his training must be at least as thorough as it is to-day.

Air Marshal Sir R. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C. (Vice-President of the Society), proposed a very hearty vote of thanks to Colonel Lahm for coming such a distance to give them an extremely interesting lecture. Twenty-one was associated with a very important event in the life of everyone; it signified the passing from adolescence to maturity, and it was particularly happy that the twenty-first anniversary lecture should be the means of drawing their attention to the importance of the human factor in the development of aeronautics. One could think of so many things where the development had been due not to the machine—great as was the debt they owed to the designers and others—but to the flyer. Spinning would occur to them all as an example, and night flying. Many would remember how, after the summer of 1917, it was considered exceedingly dangerous to fly a scout machine, such as the Camel, by night; then the pilots showed that it could be done in safety and it became a regular feature among the air squadrons in England and France. The Council of the Royal Aeronautical Society had been fortunate both in their choice of the subject and the lecturer.

Sir Richard Glazebrook, K.C.B., F.R.S., counted it a great privilege to second the vote of thanks. While he could not speak of flying with the experience of Air Marshal Sir R. Brooke-Popham, he could assure them that those who had been concerned in great measure with the development of the scientific side of aeronautics realised how much they owed to the pilot. Time after time when

investigating accidents and matters of that kind he had asked, " What could we do without them? " and had bowed down and thanked the pilots for what they had done. He remembered particularly an occasion not long since when they were examining the question of flutter, a problem the difficulty of which few realised. He (Sir Richard) occupied the Chair, and when someone suggested some fairly simple tests he turned to the pilot who had been helping them and invited his opinion. " Well," replied the pilot, " after hearing what you have said, that seems to me the best we can do at present. At any rate, I will have the machine altered and will go up and try it in the morning." That was the kind of spirit that the pilots had shown throughout. They were greatly indebted to Colonel Lahm for telling them the steps that were taken to train pilots, to help them do their work and guide them in dealing with the very difficult problems that they had to solve almost instantaneously in the air. He wondered what Colonel Lahm's original teacher would have thought of the steps that he had told them that night were necessary to train a pilot successfully, and how many teachers in that room had thought out for themselves the problem of teaching pilots to the extent and in the manner in which Colonel Lahm had done.

The 21st Wilbur Wright Memorial Lecture was followed by the Annual Council Dinner at the Hyde Park Hotel, Knightsbridge, at which the following were present:—

Mr. C. R. Fairey, M.B.E., F.R.Ae.S. (*President*), in the chair.
The Master of Sempill, A.F.C., F.R.Ae.S. (*Immediate Past-President*).

GUESTS.

Colonel F. P. Lahm, Air Corps, U.S. Army.
Air Chief Marshal Sir Edward L. Ellington, K.C.B., C.M.G., C.B.E., A.D.C., Chief of the Air Staff.
Air Marshal H. C. T. Dowding, C.B., C.M.G., Air Member for Supply and Research.
Mr. H. E. Wimperis, C.B.E., M.A., F.R.Ae.S., Director of Supply and Research.
The Lord Gorell, C.B.E., O.B.E., M.C., M.A., Chairman of the Royal Aero Club.
Group Captain P. C. Maltby, D.S.O., A.F.C., R.A.F., Commanding the Central Flying School, Royal Air Force.
Mr. H. T. Tizard, C.B., A.F.C., F.R.S., F.R.Ae.S., Chairman of the Aeronautical Research Committee.
Sir Richard T. Glazebrook, K.C.B., F.R.S., F.R.Ae.S., Past-Chairman of the Aeronautical Research Committee.
Lieut.-Colonel M. O'Gorman, C.B., D.Sc., M.Inst.C.E., F.R.Ae.S., Vice-President of the Fédération Aéronautique Internationale.
Captain H. C. Rawlings, D.S.O., R.N., Director of the Naval Air Division, Admiralty.
The Lord J. L. B. Stonehaven, P.C., G.C.M.G., C.M.G., D.S.O., J.P., D.L., LL.D., President of the Institution of Naval Architects.
Professor E. W. Marchant, D.Sc., President of the Institution of Electrical Engineers.
Mr. Griffith Brewer, F.R.Ae.S.
Captain J. W. Monahan, American Military Attaché for Air.
Commander G. D. Murray, American Naval Attaché for Air.
Major B. F. S. Baden-Powell, F.R.A.S., F.R.Met.Soc., Hon. F.R.Ae.S.

VICE-PRESIDENTS.

Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.
Air Marshal Sir H. R. M. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C.

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Mr. J. E. Hodgson (Honorary Librarian).
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Mr. M. Langley, Assoc.M.Inst.N.A., A.M.I.Ae.E.
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Mr. D. R. Pye, M.A., F.R.Ae.S.
Lieut.-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S., Director of Civil Aviation.
Sir J. D. Siddeley, K.B.E., F.R.Ae.S.
Mr. F. Sigrist, F.R.Ae.S.
Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Professor R. V. Southwell, M.A., F.R.S., F.R.Ae.S.
Mr. L. A. Wingfield, M.C., D.F.C., A.R.Ae.S.I. (Honorary Solicitor).
Captain J. Laurence Pritchard, Hon. F.R.Ae.S. (Secretary).

RECENT RESEARCH ON SPINNING

BY

A. V. STEPHENS. B.A.

(Lecture read before the Bristol Branch.)

The spinning nose dive has confronted the aeroplane designer with two main problems. The first is to evolve an unspinnable aeroplane, and the second to provide controls of sufficient power to ensure an immediate recovery from any spin into which an aeroplane can be forced. At the present time there seems little prospect of achieving a general solution of the first class of problem, although interesting particular solutions have been evolved from time to time. It seems now to be generally accepted that the unspinnable aeroplane would be desirable for every purpose, but it is evident that it must be achieved without sacrifice of performance or manœuvrability. Moreover, it must be remembered that an imperfect solution of the first class of problem, such as can sometimes be achieved by limiting the power of the control surfaces, may be worse than useless; for the pilot may be deprived of the power to regain normal flight quickly if his aeroplane falls into a spin in unusual circumstances. It is, in fact, very unfortunate that many devices which point the way to the evolution of the unspinnable aeroplane also add to the difficulty of recovery from a spin. It is not my purpose to consider the methods which have been devised to prevent the incipient spin, which occurs when a conventional aeroplane is stalled, but to confine my attention to the problems of ensuring recovery from established spins. For the views expressed I must, of course, accept personal responsibility.

In the early days of flying the spin was regarded as the prelude to a certain crash, and it was not until the middle of the Great War that it was discovered and demonstrated that recovery could be effected by correct use of the controls. It was, of course, merely fortunate that the great majority of aeroplanes of that day had controls of sufficient power under conditions so very different from those for which they were designed to operate. Towards the end of the war period there appeared certain aeroplanes which were reputed to develop " flat " spins from which recovery was very difficult, or even impossible. The tendencies in design which probably accounted for the behaviour of these aeroplanes, such as heavier loading and shorter bodies, continued for some years, with the result that vicious spinning properties have become more and more common. In consequence, consideration of the probable behaviour of new designs in spins has become of progressively greater importance. Difficulty in recovery has nearly always been associated with flat spins in which the fuselage of the aeroplane approaches the horizontal; the attention of research workers has therefore been directed mainly at discovering what particular features in design have made equilibrium possible in such a motion. Two years ago I was privileged to collaborate with Mr. H. B. Irving, of the N.P.L., in giving a paper before the Royal Aeronautical Society entitled " Safety in Spinning." In that paper we described the research work upon spinning of the previous few years, reconsidered the theory of the subject in the light of current experience, and drew up a list of recommendations for the benefit of the designer. We were, however, seriously handicapped by the limited amount of quantitative data of actual spins, and it had not been possible to apply experimental checks to all our conclusions. Our chief source of information consisted of some very comprehensive rolling balance experiments, most of which

had aimed at explaining and curing the vicious spinning properties of certain specific aeroplanes. Our knowledge of the behaviour of these aeroplanes in spins was, in general, limited to the observations of the pilots, many of whom had had no opportunity of confirming their impressions! Moreover, although it had been possible to test the effects of a number of modifications to captive models on the rolling balance, very few of these had been subjected to full-scale tests; in consequence, their respective merits under actual spinning conditions could not readily be assessed. To-day the position as regards these deficiencies has been greatly improved. In the course of full-scale tests we have been able to obtain a far more intimate knowledge of the flat spin, and we have also been able to carry out free spin experiments on a large number of different types in the R.A.E. vertical wind tunnel. Moreover, experiments on the spinning balance at the N.P.L. have made possible a more detailed analysis of the equilibrium of spins, and it is now possible to advise the designer with far greater confidence how to avoid the flat spin. Unfortunately, however, he is often unwilling to make concessions which would eliminate all possibility of a flat spin, while there are so many examples of aeroplanes which would be expected to spin badly, and yet do not; especially is this the case where precautions against spinning increase the risk of other troubles such as buffeting. Thus, although the methods of avoiding the flat spin and the factors which contribute to it are now well known, it is not very surprising that other considerations often force the designer to trust to luck as regards spinning. The percentage of present-day designs for which we should dare to predict complete immunity from the flat spin is, in fact, still small. Apart, too, from the question of equilibrium in flat spins, there remains the fact that very little is known of the actual mechanism by which an aeroplane recovers from a spin. The subject does not lend itself to simple mathematical analysis, and in consequence the application of ordinary wind tunnel data to the question of recovery is virtually impossible. In these circumstances it is clear that the value of a direct model experiment for testing the behaviour in spins of particular designs can hardly be over-estimated. I shall therefore devote the greater part of this paper to describing the technique which has been developed for testing models in the R.A.E. vertical wind tunnel. This type of experiment has the particular merit that it gives the answer in the form in which it is most required. It is of crucial importance to the designer to know whether a certain aeroplane will recover quickly from any spin it can get into, but whether the spin is flat or steep or fast or slow is relatively insignificant. By this I do not mean to say that the designer should not always endeavour to avoid the possibility of equilibrium in a flat spin, for those factors which oppose the development of a flat spin will also lead to quicker recoveries. I do not propose, however, to go into an analysis of the equilibrium of spin. This subject has been treated in great detail by Messrs. Gates and Bryant in their classic paper R. and M. 1001; it has also been reconsidered from a rather different point of view by Mr. Irving in a recent publication.

Technique of Free Model Experiments

The possibility of constructing a dynamical model of an aeroplane out of balsa wood was first demonstrated in America some years ago, but I am not aware that any results obtained by this method have been published. The experiments were conducted by dropping the models from the roof of an airship shed so that they spun freely down to the floor. Similar experiments were then started in this country. The technique was developed at the R.A.E. by the late K. V. Wright, and it is to his ingenuity and foresight that the success of the method is largely due.

The early experiments in the balloon shed led at once to interesting conclusions, but suffered from many of the same disadvantages as the full-scale experiments. It was not possible to obtain a sufficiently long spin to ensure that

steady conditions had been reached, and it was also extremely difficult to obtain accurate observations of its motion. This type of experiment served to show that small dynamical models gave a good qualitative agreement with full-scale experience in one or two specific cases, and that comparative tests of a series of modifications to any particular type could be carried out very much more cheaply and quickly than by any other method. These experiments were brought to an end by the demolition of the balloon shed at Farnborough at the end of 1930, and a suggestion was put forward to build a vertical wind tunnel in which to carry on the work. This proposal to carry out experiments with entirely free models in a wind tunnel seemed ambitious, and many doubts were expressed as to whether the models would not immediately come into collision with the walls. These were, however, dispelled by the success of a model tunnel designed by Mr. R. McKinnon Wood. It was found that the models on the whole had a slight tendency to avoid the walls, so that it was often possible to prolong the spin indefinitely. The reason for this highly satisfactory phenomenon is still a matter for speculation, and I have since heard that similar model tunnels in two other countries have not been so successful.

On the strength of the model experiment it was decided to proceed with the construction of a similar tunnel 12ft. in diameter and 30ft. high, which would be large enough to accommodate models up to 2ft. in span. A wind speed of 30ft. per second was aimed at, which required the expenditure of 50 h.p. No attempt was made to secure high aerodynamic efficiency in the first place, but recent events have shown that a rather greater wind speed would be advantageous, and a scheme for reducing the losses of the tunnel by fitting a diffuser cone on the top is under consideration. The tunnel is operated from an adjacent room, there being a large opening through which to observe the model. This opening has been found to have no adverse effect upon the flow, provided that the enclosing room is reasonably airtight. The method of launching the model in the tunnel is extremely simple. It is mounted in approximately spinning attitude upon a pivot which can be swung out on an arm from the control room into the centre of the tunnel; the controls of the model are set for spinning. The wind is then turned on and the model starts at once to autorotate. The wind speed is increased until the weight of the model is taken, at which point the latter rises off the pivot and spins freely. It is then a comparatively simple matter to adjust the wind speed to the rate of descent of the model.

The models are fitted with movable control surfaces, which can be operated by means of a delay action mechanism inside the fuselage. In the earlier experiments rudder and elevator were released and reversed instantaneously by the action of elastic strips. More recently it has proved possible to simulate a pilot's actions more precisely by causing the controls when released to operate an escapement mechanism. By these devices it is possible to test the model's powers of recovering from a fully-developed spin. A model of a satisfactory design responds immediately to the controls and dives into the bottom of the tunnel. The time it takes to do so is taken by stop watch.

As soon as the technique of testing the spinning properties of models had been evolved, it was decided to devote a proportion of the tunnel's time to testing new designs while proceeding concurrently with a more general research. Previous experiments in the balloon shed had been of mainly qualitative significance, but the proposal to gauge the safety of new designs by testing models in the tunnel at once raised the question of scale effects. It may as well be admitted at once that even the most sanguine experimenter would not expect a precise correspondence between the behaviour of an aeroplane and that of a one-twentieth scale balsa wood model. Since the spin is a gravity-controlled motion, the Reynolds number at which tests of a $1/n$th scale model are carried out is inevitably $1/n\sqrt{n}$ times that of the full-scale spin, and there is no way of increasing this value. The general consensus of wind tunnel experience would

lead us to expect scale effects at such a Reynolds number, wherever the flow round the wings approximates to the condition of maximum lift. In a steep spin the incidence across the wing span varies from perhaps 10° at the outer wing tip to 60° or 70° at the inner, and there is accordingly an appreciable area near the former where scale effects would be expected. In a flat spin, on the other hand, the whole wing is in general well above stalling incidence. There is thus a strong probability that agreement between model and full scale will be good when the spin is flat, but not so certain when it is steep. This view is well supported by a recent model experiment on the spinning balance at the N.P.L.

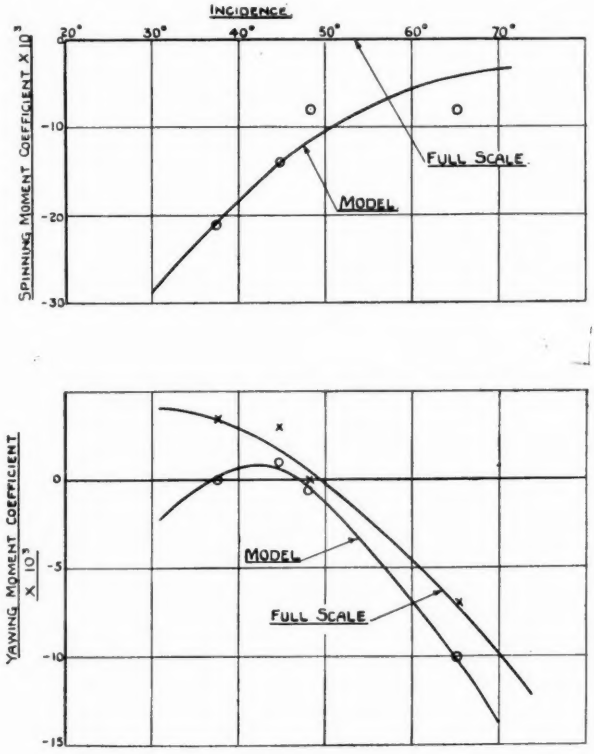


FIG. 1.

Bristol Fighter.

Comparison between Spinning and Yawing Moments for Model (1/10th Scale) and Full Scale.

In this case a one-tenth scale model Bristol Fighter was set on the balance in attitudes corresponding to those which had been observed in a series of actual spins on the full-scale aeroplane and rotated at appropriate speeds. The moments about the spinning and yawing axes were measured, with results as plotted in Fig. 1. It will be seen that the spinning moments show close agreement with full scale at 60° incidence, but a discrepancy of increasing magnitude at lower incidences. The sign of the discrepancy was such that model tests would have

been optimistic, but there is no reason to believe that this would always be the case. If it had been possible to carry out the spinning balance experiment at the still lower Reynolds number of the free spin experiments it is reasonable to suppose that the discrepancies would have been slightly greater.

Further evidence on the subject of scale effects is provided by the earliest free model tests in the balloon shed. A one-twentieth scale model Bristol Fighter, and a one-fifteenth scale model of a single-seater fighter, were both found to have two conditions of equilibrium in a spin, one flat and the other steep. On the other hand, full-scale experience of both types indicated that for loadings corresponding to these tests only the flatter type of spin was stable. A scale effect such as that disclosed on Fig. 3 might well account for these discrepancies. A large unfavourable moment at about 30° incidence would have been sufficient to prevent the transition from a steep spin to a flat one; but when the model was launched in a flat spin it would have reached a condition of equilibrium approximating closely to the full scale. It has always been our practice to launch models in the vertical tunnel in flat spinning attitudes so that the tests cover the most formidable spin which can occur for a given loading. Where a model exhibits both steep and flat spinning tendencies, it is our policy to assume that the latter are more likely to occur at full scale, and to take action accordingly. From the foregoing it will be evident that any spinning test of a new design must be arranged to allow some margin to cover the possibility of aerodynamic scale effects. There are, however, other considerations which have also to be borne in mind. It is now realised that many existing aeroplanes, although normally quite well behaved in a spin, have very little margin of safety; small changes in loading or rigging have been known to lead to dangerous flat spins in isolated cases. In this connection it must be remembered that a balsa wood model cannot be relied upon to maintain an accuracy greater than perhaps ½° in the wing incidence, for example; also that its moments of inertia correspond to values calculated from a weight schedule, which may often be in error by as much as 10 per cent.

Another source of uncertainty arises in the case of slotted aeroplanes. At the present time it is not possible to predict with certainty whether automatic slots will remain open during all types of spins. In many cases they have been observed to do so, but there have also been isolated occasions upon which one or both have shut. As it is not feasible to represent the link mechanism of the slots on the small scale of the balsa wood models, it is considered wisest to test a model under all combinations of slot settings. In this connection it has been pointed out that as long as the slots have an influence upon the spin, the aerodynamic forces will be such as to tend to hold them open; but they may be overcome by components of centrifugal force in certain types of spin. The uncertainty as to mass distribution is covered by doing a series of spinning tests to find out the effects of increasing the moments of inertia A and B by weighting wings and fuselage respectively. The effect of changing the C.G. position is also investigated. Having determined the effects of the various parameters upon the ease with which the model will recover from a spin, it is our practice to form a " worst case " in which all unfavourable factors are combined. The extent to which moments of inertia and C.G. positions are varied from the standard condition are made greater than is likely to occur in practice, so that some margin is left to cover scale effects and inaccuracies of the rigging of the model.

The standard of recovery required with the model loaded in this way is roughly the same as is required in routine spinning tests at Martlesham; the time of recovery must not exceed a period corresponding to eight seconds full scale when controls are reversed against the spin. Only experience will show whether this standard is sufficiently stringent to anticipate all spinning troubles;

to those who argue that it is too strict a test, I would like to point out that only 20 per cent. of the new designs which have been tested in this way have failed to reach the requisite standard. The proportion of unsatisfactory designs shown by Martlesham statistics for thirty different types, tested between 1927 and 1930, was 27 per cent. In any case, it has nearly always proved possible to modify an unsatisfactory model so as to make it pass the test, in a way which would not be expected to impair its characteristics in normal flight.

Ample justification for the procedure which has been adopted for routine testing of models is to be found in the results of subsequent experiments on models of several aeroplanes, whose behaviour in spins has been definitely established.

A particularly illuminating experiment correlated model results with full-scale experience of a seaplane. In the course of full-scale tests at Felixstowe the seaplane, although lightly loaded and with C.G. well forward, developed a flat spin from which recovery could not be effected. The pilot and observer escaped by parachute and stated that both rudder and elevators had been applied fully against the spin. Model results were at first perplexing, for it was found that, with the model loaded to have moments of inertia corresponding to the calculated values, a steep spin was obtained with the forward position of the C.G.; recovery was immediate when the controls were reversed. When the C.G. was moved back to the position corresponding to normal full load a flatter spin was obtained, but recovery could be effected in time corresponding to five seconds full scale. Further experiments, in which the wings of the model were loaded, at once revealed the vicious spinning properties of the type; with A* increased by 20 per cent. and the normal C.G. the model spun faster than before, and did not recover when the controls were reversed. On the other hand, with only a 10 per cent. increase in A, and the same C.G. position, recovery was rapid. For these tests the model had not been fitted with slots, although these were in operation upon the seaplane at Felixstowe. When the tests were repeated with open slots, only a 10 per cent. increase in A was necessary to render recovery impossible, although under normal load recovery was still rapid. The experiment demonstrates clearly the importance of varying the loading of the model before any pronouncement as to its safety in a spin can be made. In two cases a change of 10 per cent. in A made the difference between a rapid recovery and none at all. Implicit faith in an exact correspondence between the model and full scale would have led to the erroneous conclusion that the aircraft would recover easily from a spin; but the "worst case" criterion adopted for routine tests could not have failed to anticipate the dangerous characteristics which were so convincingly demonstrated at Felixstowe. The experiment raises a further point of great importance; it appears that very satisfactory spinning qualities under one loading are no guarantee that great difficulty in recovery may not be experienced under another.

In another experiment of great interest the failure of a low-wing monoplane to recover from a spin in the course of routine spinning trials at Martlesham was investigated in the vertical wind tunnel. At first little surprise was expressed at the full-scale result, in view of the fact that the monoplane combined a large negative value of A-B with a fuselage of circular cross section and a badly-shielded fin and rudder. It transpired, however, that the firm's pilot had carried out a number of long spins and had experienced no difficulty whatever in recovering from them. The model experiments at once confirmed his experience. Under all loads, within the limits of inertia and C.G. position adopted for routine tests, the model spun in a steep attitude and recovery on reversal of the controls was instantaneous. It was discovered, however, that if the elevators were moved down by 10° or more from the hard-up position, the model at once developed a flat spin from which recovery was often extremely slow, if not actually impossible.

* Throughout this paper the moments of inertia of an aeroplane about the longitudinal, lateral and normal axes are referred to as A, B and C respectively.

In the Martlesham pilot's report of the accident it was stated that the spin only became flat after he had temporarily released his hold upon the stick. He stated that the stick remained back during this period but it was considered unlikely that he would have detected a forward creep of two or three inches. On this hypothesis the model results showed a precise agreement with full-scale experience. This experiment raises a further point in connection with spinning tests of both aeroplanes and models. It appears that a design which is insensitive to variations in mass distribution may yet be highly sensitive to a small movement of the elevators. Spins with stick forward will be investigated in all future model tests, and I should advise any pilot who is testing out a new design to do the same. Should this provoke a flat spin in which subsequent reversal of the rudder has little effect, recovery should in general be possible by pulling back the stick and maintaining full opposite rudder. The model tests of the low-wing monoplane referred to above, indicated that recovery should have been possible if the pilot had persevered with this method for perhaps 15 seconds.

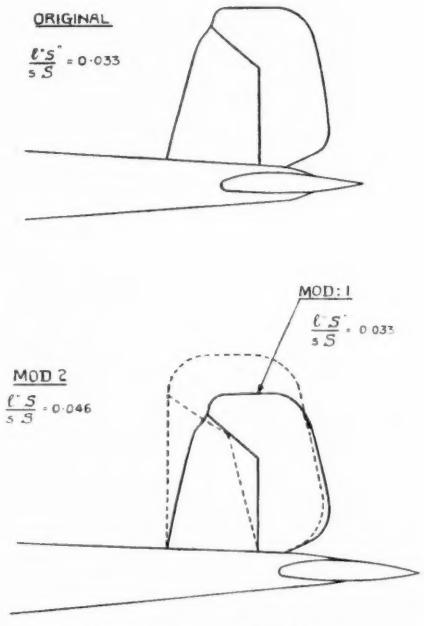
Another interesting comparison between spinning model and full scale was the case of the Pterodactyl Mark IV. In the absence of any relevant rolling balance data it was quite impossible to predict how the aeroplane would spin, or whether the controls on the wing tips would prove adequate for recovery. Model tests were therefore carried out before any full-scale spinning was attempted. It was found that the model had very satisfactory spinning properties, but showed many peculiar features; in particular, spinning was not possible unless the lateral control was applied in the direction of the spin. Recovery could be effected instantly on centralising the ailerons or by moving the stick fully forward; but there was little response to reversal of the rudders. All these idiosyncrasies were confirmed in subsequent full-scale tests. Reviewing all the evidence, it appears that a dynamical model of 2ft. span can be relied upon to reveal the spinning properties, however unusual, of any design. It is, however, essential to cover a range in inertia variation and C.G. position wider than is likely to be realised full scale before any opinion can be expressed as to its powers of recovery.

Routine tests on the lines described above have now been carried out on models of between fifteen and twenty different types. The results on the whole bear out well the theories which have been based upon rolling balance data and early full-scale experiments. It will be remembered that the main conclusions at which we arrived two years ago were, first, that the flat spin could best be avoided by unshielding the fin and rudder; this could most easily be done by raising the tail plane. Secondly, that the difference A-B between the moments of inertia about the longitudinal and lateral axes would have a large influence upon the tendency of an aeroplane to spin flat.

A-B positive, that is weights in the wings, would make an unstaggered biplane tend to spin flat, but A-B negative would be bad in the case of a monoplane or highly-staggered biplane.

From the free-spin experiments there is abundant evidence that dangerous spinning properties can be cured by the provision of an unshielded rudder; the area required varies with the mass distribution of the design, but only becomes of unusual size if the wing inertia combination is markedly unfavourable. On the other hand, a very large fin and rudder situated directly above the tailplane may prove quite inadequate. As regards the moments of inertia, it now appears that it is not always the difference A-B which is the dominating factor. The position is also complicated by the appearance of automatic slots, which affect the rolling characteristics of biplane wings in the same way as a reduction of stagger. It has, however, been established that the effect of loading the wings of a slotted biplane is unfavourable if the stagger is 20° or less. Loading the fuselage is in general favourable in these cases, but there have been one or two notable exceptions. In particular, a slotted twin-engined biplane with 9° stagger

was very susceptible to weights in the fuselage, but only slightly so to the addition of further weights in the wings; increasing A or B led to an increase in time of recovery. Monoplanes were found to be highly sensitive to increases in the inertia of the fuselage, but relatively indifferent to weights in the wings. Biplanes of 30° stagger were in general insensitive to mass distribution. As regards C.G. position: it was found that nearly all types were made worse by backward movement of the C.G., but a low-wing monoplane and a highly-staggered biplane in both of which cases A-B was large and negative were worse with C.G. forward.



TAIL UNITS OF AEROPLANE X

FIG. 2.

The effect of automatic slots was not confined to their influence upon the response of a model to changes in mass distribution. Their value in preventing the incipient spin, when an aeroplane is stalled is well known. Unfortunately this beneficial influence falls off as the spin gets flatter until at 45° incidence or more they actually aggravate the flat spinning tendency. There is also the possibility of the slot upon the inner wing closing in a spin in which case the unfavourable effect may be greatly increased. Thus, as far as recovery from spins is concerned, slotted aeroplanes will require more effective rudder area than unslotted ones.

I shall illustrate these points by one or two examples. Fig. 4 shows three versions of the tail unit which were tested on a low wing monoplane. It will be seen that in the first the rudder was just above the tailplane; in the second and third the tailplane was moved back behind the rudder; and in the third the area

of the latter was increased by roughly 40 per cent. Fig. 3 shows the times of recovery of the three versions of the model plotted against $C\text{-}A/ms^2$* (which appeared in this case to be the most important factor) for the case in which the outer slot only was open. It will be seen that loading the fuselage, that is increasing $C\text{-}A$, increased the time of recovery in each case. But the curves for the original version of the design are very much the steepest. The actual value of $C\text{-}A/ms^2$ was in the neighbourhood of .03, from which it will be seen that while the original might well fail altogether to recover from a spin, either of the modified versions had a fair margin of safety, although the first might not recover very quickly. The effect of C.G. position in increasing time of recovery may be seen by comparing the two curves for the original design.

Another example of the way in which redesign of the tail organs can eliminate a tendency to spin flat is given in Fig. 4. It shows the tail unit of the low wing monoplane which I previously referred to in conjunction with two modified versions, which have also been tested in the vertical wind tunnel. Here it will be remembered the flat spin was only developed if the elevators were moved down before the rudder was reversed for recovery. The original model failed entirely to recover from a flat spin so induced under the loading corresponding to the worst case of a routine test. Both modifications, however, prevented the flat spin from occurring and recovery on reversal of the rudder could be effected

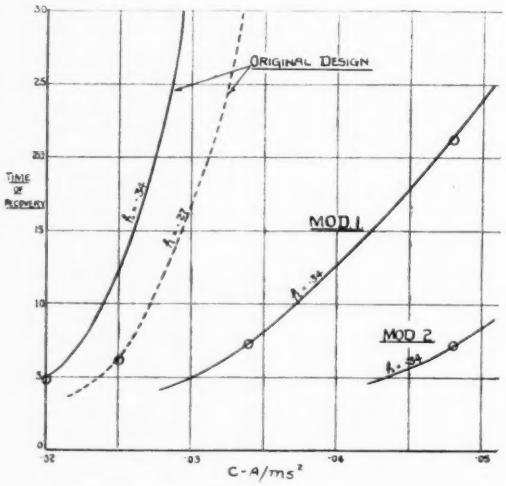


FIG. 3.
Spins of Model X.
Inner slot closed.

in times corresponding to less than 5 seconds full scale. The case is of particular interest, because it shows that even a very large fin and rudder situated directly above the tailplane may be totally ineffective in a flat spin. Another point of interest is that the fuselage in this design was unusually long in comparison with the wing span. This, in itself, might have been expected to prevent the development of a flat spin, but it has recently been shown on the rolling balance that a fuselage of circular cross-section tapering to a point offers practically no resistance to rotation in a flat attitude.

* m = mass of aeroplane, s = semi-span.

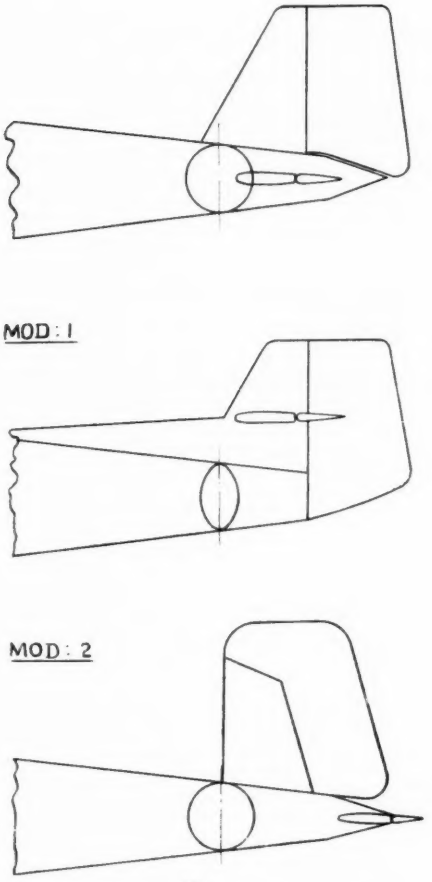


FIG. 4.
Aeroplane Y $l''S''/sS=0.088$.

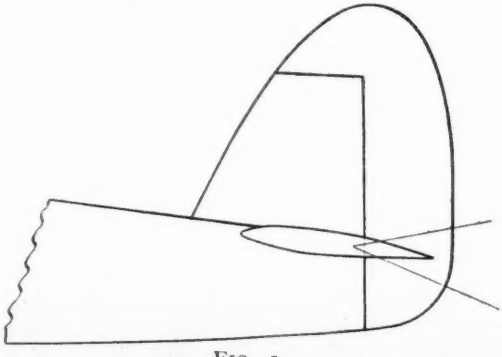


FIG. 5.
Tail unit of aeroplane Z.

One further example is of interest. Fig. 5 shows the tail unit of a slotted biplane with 21° stagger. This model was found to be extremely sensitive to A-B. Fig. 6 shows the times of recovery for a particular C.G. position plotted against $A\text{-}B/ms^2$. The curves show clearly that with both slots open, the model had two types of spin, one flat and the other steep. Recovery from the latter was rapid, but the former slow. With only the outer slot open recovery was slower still. The extreme sensitivity of the time of recovery to mass distribution must again be attributed to the ineffectiveness of the rudder under the conditions of a flat spin. An obvious cure would be to raise the tailplane.

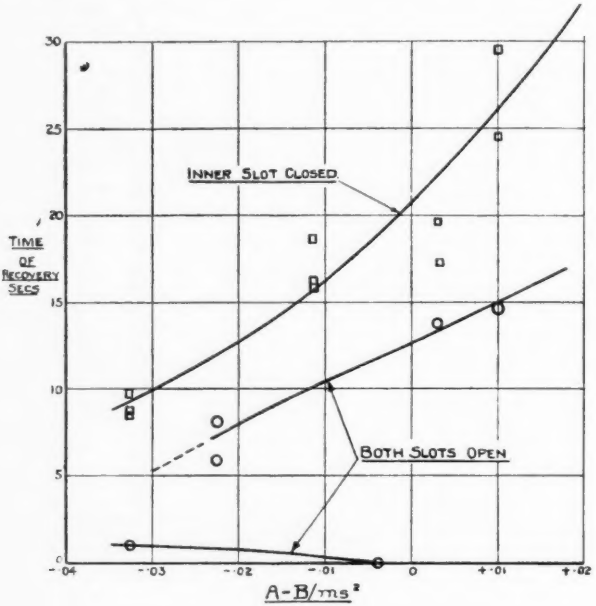


FIG. 6.

Spins of model Z.

$h = .395$.

I have, I think, now given sufficient examples of designs which were bad from the point of view of spinning to enable me to name the principal features which it is desirable to avoid. They are

(1) A fin and rudder directly above the tailplane.
(2) Weights far out on the wings of a biplane of little or moderate stagger.
(3) Weights in the fuselage far from the C.G. of a monoplane.
(4) A fuselage of circular cross-section near the tail.
(5) A C.G. position far back in relation to the wing chord.

Of these the first is by far the most important, since bad cases have been obtained even where the wing inertia combination is favourable. It is particularly important if slots are fitted and also if it is impossible to avoid one or other of the remaining bad features.

As regards the moments of inertia, I do not feel justified in suggesting that the undesirable features which I have laid down can be compensated by distributing the remaining available masses along the fuselage of a biplane or the wings of a monoplane. This, in any case, is very seldom feasible and might in some circumstances actually make matters worse. In the same way with regard to C.G. position, a backward C.G. position is nearly always had, but a very far forward one may also be undesirable in conjunction with a bad wing inertia combination.

To sum up: Dangerous spinning properties can be eliminated with all reasonable certainty if all the above mentioned bad features can be avoided; but in any case, where the greater part of fin and rudder is directly above the tailplane, there is an uncertainty which can best be dispelled by a direct trial in the vertical wind tunnel.

ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Regular abstracts of Patent Specifications received by the Society will be published in future in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

These abstracts are compiled by permission of the Controller of His Majesty's Stationery Office. Official Group Abridgments can be obtained from the Patent Office, 25, Southampton Buildings, London, W.C.2, either sheet by sheet as issued on payment of a subscription of 5s. per group volume or in bound volumes 2s. each, and copies of full specifications can be obtained from the same address, price 1s. each.

Aerodynamics, Stability and Controllability

397,805. *Improvements in or Relating to Automatic Steering Apparatus for Aircraft.* Askania-Werke Aktiengesellschaft vormals Centralwerkstatt Dessau und Carl Bambergfriedenau. Kaiserallee 87/88 Berlin-Friedenau, Germany. Convention date (Germany), April 20th, 1932.

The statement is made that when an aircraft is inclined with reference to its longitudinal axis, by, for instance, a gust of wind, it deviates from its course, and further, that the course is influenced by the inclined positions which an aircraft must assume on a curve. The influences which the inclined position of an aircraft exerts on the course steering make themselves noticeable in an objectionable manner, particularly in the case of automatic course steering.

It is proposed to overcome this difficulty by arranging that the lateral steering is additionally influenced by an impulse derived from the turning velocity of the aircraft about its longitudinal axis. The apparatus is to be adjustable so as to suit different aircraft and it is stated that if the lateral steering is influenced by a gyroscope with two degrees of freedom and axis of rotation parallel with the aircraft transverse axis, the invention can be so carried out and applied that the influence derived from the turning velocity about the longitudinal axis is applied against the precession influence of the gyroscope. The impulse to be derived from the turning velocity about the longitudinal axis can also be derived from a gyroscope with two degrees of freedom. The precessional effects of both gyroscopes can be caused to act on a relay. The drawing shows a compressed air relay operated gyroscopically.

398,069. *Aeroplanes with Auto-stable Arrangements of Planes.* Albessard, J., 31, Rue du Laos, Paris, France. December 13th, 1932. No. 35,352.

It is proposed to take advantage of the upward velocity of the air on the outer sides of the wing tip vortices of an ordinary aeroplane wing by placing additional wings behind the main wing tips so that they operate in these upward currents. This arrangement is claimed to increase the safety of aircraft and also to lead to easy control, impossibility of nose-diving, side-slipping, etc., and also to cause resistance to rolling and pitching in squalls.

The drawings show numerous arrangements of aircraft wings constructed in accordance with the specification.

399,048. *Improvements in or Relating to Aeroplanes having Surfaces Variable During Flight.* Gerin, J., 24, Rue de la Tourelle, Boulogne-sur-Seine, France. Convention date (France), December 9th, 1931.

This refers to the type of variable area wing in which the area is varied by extending the chord of the wing. It is stated that the fixed portion of the wing is adapted to lift the aeroplane at high speeds, while the portion to be extended out has a great curvature in order to have a very high lifting action.

Aeroplanes, Construction

397,497. *Improvements in or Relating to Aircraft Wheel Brakes.* The India Rubber, Gutta Percha and Telegraph Works Co., Ltd., Aldwych House, Aldwych, London, W.C.2, and Tarris, F. J., of the Company's Works at Silvertown, London, E.16. February 23rd, 1932. No. 5,420.

Aircraft wheel brakes are described so that the wheels may be braked simultaneously for checking the speed of the aircraft or differentially for steering purposes. When the brakes are used for steering they are operated by the pilot's rudder bar.

The brakes are operated by compressed air and there are two apparata each containing two cylinders. These cylinders are operated through linkage which, in turn, is operated by the rudder bar. These two apparata are placed one each side of the rudder bar and cause the brakes to be applied on either wheel so that the steering of the aircraft on the ground is in the normal direction. The two cylinders act so as to cause the air pressure to be raised or lowered in each wheel brake as required.

The air pressure is supplied from an outside source and an arrangement is described, operated by one lever, by which the apparatus can be cut out or cut in as desired by the pilot.

397,895. *Improvements in Aircraft Wheel Braking Systems.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1. Goodyear, E. F., Wright, J., and Trevaskis, H., of the Company's Works at Foleshill, Coventry. December 2nd, 1931. No. 33,370.

This wheel brake arrangement is stated to enable delicate degrees of brake application to be effected with minimum effort. The braking force is transmitted by means of compressed air, the distribution of the compressed air to the two wheels being effected by an arrangement consisting of two relays arranged in a V. The relays are controlled by links operated from a sliding member placed about in the angle of the V, and this sliding member may be displaced radially by a connection to the rudder bar so that one relay is moved more than the other when the rudder bar is displaced, thereby transmitting a differential pressure to the brakes. The sliding member is controlled from the control stick of the aeroplane by means of a short lever connected to the sliding member by means of a Bowden cable, or by rod and link work.

397,896. *Aeroplane Brakes and their Controls and Valves Therefor.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1. Goodyear, E. F., Wright, J., and Trevaskis, H., of the Company's Works at Foleshill, Coventry. December 2nd, 1931, No. 33,371, and July 16th, 1932, No. 20,184.

The specification deals with relay valves and the arrangement thereof for the purpose of operating aircraft brakes together and differentially. Applications 33,370/31 (Serial No. 397,895) and 33,372/31 (Serial No. 397,897) are referred to.

There is described a method of operating relay valves for compressed air brakes by arranging them in a V and controlling them by means of a sliding member located in approximately the angle of the V. This sliding member may be displaced radially by means of a connection to the rudder bar so that the degree of operation of the relays may be varied differentially, causing differential application of the brakes.

The specification describes in detail the type of relay it is proposed to use, a yielding diaphragm, in addition to inlet and exhaust valves being operated by the control. This is arranged so as to enable the air pressure distributed to the two wheels to be varied in accordance with the control movement used by the pilot.

397,897. *Aeroplane Brakes and their Control.* The Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1. Goodyear, E. F., Wright, J., and Trevaskis, H., of the Company's Works at Foleshill, Coventry. December 2nd, 1931. No. 33,372.

Pneumatically operated aircraft brakes are described in which the relays are arranged in the form of a V and are operated by link gear from a point approximately in the angle of the V. This operation is effected by means of a sliding member in a guideway capable of being displaced radially so that the two relays are differentially actuated, with the result that the air pressure is differentially distributed to the aircraft wheels. The radial displacement of the sliding member and guideway may be effected by a connection to the rudder bar, while the operation of the sliding member in the guideway is controlled by the pilot by means of a small lever attached to the control stick.

Reference is made to Applications 33,370/31 (Serial No. 397,895), 33,371/31 and 20,184/32 (Serial No. 397,896).

398,892. *Fluid Pressure Brakes for Aircraft Wheels.* Vickers (Aviation), Ltd., and Duncan, T. S., both of Weybridge Works, Byfleet Road, Weybridge. March 24th, 1932. No. 8,785.

It is stated that in the case of wheel brakes for aircraft means must be provided to enable the braking force to be applied differentially to the wheels so that the machine may be steered on the ground. At the same time the maximum braking power must be limited so as to remove all risk of the machine overturning when the brakes are applied. It is, however, necessary to provide greater power when the aircraft is stationary to permit of the engines being run up while the aircraft is on the ground.

This specification describes a method by which fluid pressure can be distributed to the wheel brakes through pedal controlled reducing valves, so that limited braking pressure corresponding to the depression of the pedals is produced differentially in the wheels. At the will of the pilot the full pressure may be applied directly to the brakes for parking or running up engines.

The arrangement shown in the drawings consists of a reducing valve controlled by a diaphragm which is acted on by the pedal through a spring. This diaphragm controls both inlet and exhaust valves, and the pressure distributed to the brakes depends on the pressure applied to the pedal.

There is a device operated by a lever which enables the pilot to cut out the reducing valve and admit pressure directly to the brakes, this is used for parking purposes and when it is desired to run up the engines.

397,964. *Improvements in or Relating to Aeroplanes.* Airspeed, Ltd., and Tiltman, A. H., both of Piccadilly, York, Yorkshire. April 27th, 1932. No. 12,088.

The specification refers to a retractable undercarriage arranged to be folded into an aeroplane wing. The undercarriage structure consists of an approximately vertical shock-absorber strut, a diagonal strut for lateral support, running inwards and upwards from the stub axle carrying the wheel and another strut running backwards and upwards to the wing from the axle for longitudinal support. One such structure is used for each wheel in a normal aeroplane.

The retractable arrangement consists in introducing into the strut running backwards a joint similar to that of a perambulator hood support. The point where the joint is fitted in the strut is attached movably to a hydraulic ram, the other end of which is attached to the wing at a point higher than that of the strut attachment. On introducing pressure into the ram in such a direction as to shorten it, the undercarriage is caused to retract into the wing. An arrangement is referred to whereby the aeroplane may land without severe injury with the undercarriage retracted.

398,244. *Tailless Aeroplane.* Langguth, W., Stuttgarter-Strasse am Walde, Böblingen, i/Worttemberg, Germany. March 11th, 1932. No. 7,303.

In order to reduce the bending movements of the wing spars of an aeroplane, thereby saving weight, the inventor proposes to distribute the load, in combination with the weight of the wings, over the length of the wings approximately in the same proportion as the lift forces. An arrangement by which at least one spar in each wing is adapted to be used as a magazine or chamber for the useful load is also claimed.

The drawing shows an aeroplane consisting simply of an aeroplane wing, which is arranged in V form in the plan.

398,411. *Retractable Landing Gear for Aircraft.* Dornier Metallbauten G.M.B.H. and Dr. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date (Germany), April 26th, 1932. Application date (United Kingdom), February 23rd, 1933. No. 5,591.

This is a retractable undercarriage for high wing monoplanes, the undercarriage being drawn into the fuselage. A vertically disposed screw-threaded spindle is arranged in the fuselage and the fulcrums of the movable members of the undercarriage are carried by a nut adapted to travel on the screwed spindle so that when the nut is screwed to the top of the spindle the undercarriage is wholly or partly within the fuselage. The undercarriage in the opened out position may be secured in position by means of ropes, or the like, secured at one end near the hub of the landing wheels, at the other end to the wing of the aircraft, being arranged to be tightly stretched when the landing gear is in its lowest position.

396,956. *Improvements in or Relating to Undercarriages or Landing Gear for Aircraft.* Dornier Metallbauten G.M.B.H. and Dr. Ing. C. Dornier, both of Friedrichshafen, Lake Constance, Germany. Convention date, December 8th, 1931.

This folding undercarriage is of the type that projects laterally from the lower part of a fuselage, and the wheels and axles are arranged to fold in a direction transverse to the longitudinal axis of the aeroplane, the wheels being

approximately parallel with each other during the folding process. The final result is that the wheels lie flat in recesses in the sides of the fuselage.

A frame is fitted within the fuselage which is fitted with slots which act as guides during the displacement of the undercarriage. This frame or guiding device is a rigid member and is forced by springs or other resilient devices into open V-shaped bearings which are positioned as far as possible from the centre line of the aircraft. Locking pawls and a rope raising and lowering device are also described.

Aircraft, Military

397,433. *Device for the Feeding of Cartridges in Automatic Firearms.* Societe Anonyme des Anciens Etablissements Hotchkiss et Cie, 6, Route de Gonesse, St. Denis (Seine), France. Convention date (France), January 21st, 1933.

This specification refers to the feeding of cartridges into machine-guns, especially when situated in the wings of aircraft. It is pointed out that the tractive effort required to draw a long band of cartridges into the gun is considerable.

The inventors propose to overcome this difficulty by disposing the cartridge band in the form of a hairpin, the bend consisting of a large pulley. The band is sloped down from the top of the pulley to the gun so that the feed is assisted by gravity. The degree of the slope is made as great as possible consistent with the thickness of the wing in which it is placed.

Airscrews

397,027. *Improvements in Endless-Track Propellers for Marine Vessels or Aircraft.* Phillipp, H., Paracelsusstrasse 13, Salzburg, Austria. Date, February 8th, 1933. No. 3,827.

This describes a form of paddle propeller in which the paddles are connected to an endless chain instead of to a wheel. The specification describes means by which the paddles can be brought into the working position, secured, and again released into a freely swinging position where the resistance is nearly eliminated. It is stated that the arrangement can be used when the paddle chain is entirely submerged.

Autogiros

397,120. *Improvements in Flying Machines and in Apparatus for the Propulsion of Fluids.* Pitter, W. C., 59, Bower Hill, Epping. February 15th, 1932. No. 4,430.

This arrangement is described as a modification of the "Autogiro," and use is made of radially arranged wings freely rotatable, as heretofore, about a vertical axis; the wings, however, being so constructed that they will be transversely flexible or movable each about its own longitudinal axis. The radial wings are described as being flapped or oscillated to and from the vertical axis about hinges or pivots which are carried by a freely rotatable sleeve. It is stated that by arranging the wings near the same plane and operating them in such a manner that some are oscillating upwards while others are oscillating downwards, the descending wings will meet a supporting current of air caused by the wings oscillating upwards.

Balloons

397,347. *Improvements in Captive Balloons.* Letourneur, J., 75, Rue de la Parcisse, Versailles (Seine et Oise), France. Convention date (France), November 27th, 1931.

This deals with a method of constructing the fins of kite balloons, which fins are kept extended by means of air introduced by scoops. It is pointed out that the geometrical surfaces that it is possible to obtain with a fabric held taut by internal pressure are limited, as the surface has to be under tension at all points. The fin proposed has the general form of the usual type, but its exterior contour is composed of a cylindrical surface. The space between the envelope and this surface is filled with portions of cylinders of revolution, the radii of which decrease towards the rear.

Dopes and Fabrics

398,156. *Improvements in or Relating to the Coating of Fabrics.* E. I. Du Pont de Nemours & Co., Wilmington, Delaware, U.S.A. Convention date (U.S.A.), December 3rd, 1930. Application date (in United Kingdom), December 3rd, 1931. No. 33,543. Complete not accepted.

This specification deals with the composition of dopes for coating aircraft fabrics, loud speaker cones, etc., and it is proposed to substitute cellulose ethers, such as benzyl cellulose, ethyl cellulose, and crotyl cellulose, for the more usual cellulose acetate and cellulose nitrate in the composition of these dopes.

A suggested formula for a first coat is—

Benzyl cellulose	16	parts	by weight.
Denatured alcohol	24	,,	,, ,,
Toluol	60	,,	,, ,,

A suggested formula for a top coat is—

Benzyl cellulose	14.5	parts	by weight.
Pigment	10	,,	,, ,,
Plasticiser	10	,,	,, ,,
Toluol	40	,,	,, ,,
Xylol	12	,,	,, ,,
Glycol monomethyl ether	6	,,	,, ,,
Denatured alcohol	17.5	,,	,, ,,

A further suggested formula is given for a top coat containing cellulose acetate in addition to benzyl cellulose.

Engines

392,949. *Improvements in Engine Mountings.* Trott, R. S., 704, Equitable Building, Denver, Colorado, U.S.A. November 16th, 1931. No. 31,670.

This is a mounting intended to smooth out the variable torque of a petrol engine and so to prevent vibration occurring. It consists of providing two points of support for the engine, including, if desired, the gearbox. These points of support are arranged longitudinally and take the weight of the power plant, one at least of them is to be of non-metallic and resilient material and permitting of a movement of the unit with reference to the frame.

A separate resilient connection is made to the frame for the purpose of transmitting torque. Various types of resilient connections are described and shown in the drawing, some depending on rubber and others on spring devices. A drawing is also given showing the application of the mounting to an aero engine.

Jet Propulsion

397,992. *Devices for Propelling by Reaction.* Rey, J. A., 30, Rue de Versailles, Viroflay (Seine et Oise), France. Convention date (France), June 25th, 1931.

A jet propulsion arrangement is described, stated as being suitable for the propulsion of rockets, vehicles, ships or the like. The propulsion is effected by means of the reaction of ejected fluids in which the propelling fluid is allowed to expand in an enlarging passage and draws in additional fluid in one or two stages prior to ejection. It is stated that more than two fluids can be used; for example, in the propulsion of a ship it is proposed to use steam to draw air into the first duct, the mixture of steam and air being used in a second duct into which it draws sea water.

The drawing shows a taper nozzle provided with lateral passages for the introduction of the additional fluid or fluids.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—I notice that in the new syllabus for the Mechanics of Fluids for the B.Sc. examination of the University of London reference is made to the Prandtl aerofoil theory. The syllabus referred to is published in the Monthly Notices issued with the last number of the Journal of the Society.

This particular theory was originated by an Englishman, Dr. Lanchester. Dr. Prandtl's work in connection with it consisting of a general development. Under these circumstances I would suggest that the theory be referred to as the Lanchester-Prandtl theory in all official publications as is, I believe, the German practice.

Yours faithfully,

W. O. MANNING.

12th October, 1933.

REVIEW

Amateur Pilot

By the Earl of Cardigan. Published by Putnam. Price 7s. 6d.

For the first time we older hands have been told, in writing, exactly what the modern amateur pilot thinks about aviation and the process of learning to fly. We learn what it feels like to be instructed, what he thinks of instructors, and what he thinks of the modern light aeroplane. The author also analyses his sensations while flying, from the first flight with the instructor to the continental tour, and we can share with him the fears and joys of the first circuit as well as the long struggle with the elusive problem of making a good approach, followed by a 3-point landing.

There is also the story of his first continental tour. His somewhat inauspicious start for France, ending at Biggin Hill, and his second and successful attempt to cross the channel, his struggles with officials complicated by the language question, and the eventual success with the return to England are told well. The author has a knack of description and a well-developed sense of humour.

The last chapter dealing with the aeroplane of to-morrow deserves to be read by all who are interested in the development of the light aeroplane. At present the aeroplanes available for the use of such pilots as the Author are what the constructor, advised by a highly skilled test pilot, thinks he ought to want. In future the amateur pilots will settle for themselves the sort of aeroplane they want, and the resulting machines will differ materially from those in use to-day. It would be well worth while for a firm to appoint a thoroughly unskilled pilot to do test work; they would learn facts about their aeroplanes which their expert could never tell them, for the latter would not make the preliminary mistakes.

The Earl of Cardigan has done a real service to the light aeroplane movement by writing this book.

The 566th Lecture delivered before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS

First Meeting, First Half, 69th Session

The First Meeting of the 69th Session of the Royal Aeronautical Society was held in the Lecture Theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, October 12th, 1933, when a paper on "Air Traffic Control" was presented by Major R. H. S. Mealing.

Colonel the Master of Sempill (Past-President of the Society) in the chair.

The Chairman: For the last eight years or so Major Mealing had been Chief Technical Assistant to the Directorate of Civil Aviation. His experience, both practical and in a general administrative way, in regard to military and civil aviation was considerable, and he would speak as the principal individual in this country concerned with watching these matters and framing the various regulations.

AIR TRAFFIC CONTROL

BY

MAJOR R. H. S. MEALING

(Chief Technical Assistant, Directorate of Civil Aviation, Air Ministry)

When I was first asked by your President to read a paper on "Air Traffic Control," I had for so long been dealing with the problem, at least as we see it in this country, that I thought I knew something about the subject and accordingly accepted the invitation.

When I came to analyse my ideas and put them on paper I discovered that, as with so many other new subjects, it was one on which one could dilate and debate at great length, but also one in which it was extremely difficult to make suggestions, far-reaching or otherwise, and yet remain practicable.

I have no intention of propounding any new and far-reaching proposals, but rather do I prefer first of all to ask, is there any such problem and then how should it be dealt with?

There certainly exists a number of people who don't like control of any sort and particularly with regard to aviation; so when I asked a friend of mine, well-known to all of you, if he had any ideas on the subject of air traffic control to help me write a paper his sole reply was, "Better call it lack of control."

When I tell you that he is not an air-line pilot but a well-known test pilot, I suppose one must admit that such a problem does exist and apparently is one which must be tackled.

I make this introduction in no spirit of levity but rather as an explanation of the fact that, in spite of the present rules of the air, one must apparently accept the fact that further control is needed.

Before one attempts to define the problem I think one must divide the subject into two parts:—

(*a*) The control of traffic in the air;
(*b*) The control of traffic on the ground.

It will be agreed, I am sure, that the control of traffic on the ground and the problem which arises therefrom is completely analogous to the control of maritime traffic on and in the vicinity of harbours.

But the control of traffic in the air is something which is not in any manner analogous to any other form of transport.

So far as I can recall, there is no other form of vehicle used in transport which cannot stand still when it is necessary to do so, and it is from the incapability of an aeroplane to remain stationary that arises the risk of collision—collision with another aircraft or collision with some obstruction on the ground should it be flying so low.

The aeroplane also suffers from the disadvantage that within the limits of its power to climb, it can fly at any horizontal plane and thereby does it very seriously complicate any system devised to avoid collision.

When one remembers that every surface vehicle—either land or water—remains on one plane, but that an aeroplane can and does fly on several different planes, one hesitates to suggest whether the control of surface vehicles is a very simple problem or that the control of air-borne vehicles is a very difficult one.

I will later on endeavour to show, however, that from practical experience we have learnt to make use of the varying heights at which aircraft can fly to simplify the method of control.

Whilst one can examine the two problems of control in the air and control on the ground separately one must remember that they are very closely related, inasmuch as we now accept as a basic rule that priority must always be given to the machine in the air and under no circumstances must a machine on the ground be allowed to endanger the machine in flight.

Beyond that point one must treat the requirements for control in the air and control on the ground as two separate entities.

So far as control in the air is concerned, I must admit that in my introduction I stated that I had no intention of propounding any startling theories, but one theory which I am going to propound is one which by long consideration I am convinced is right and is not really at all startling.

It is this—having regard to the necessity of air transport proving itself, not by speed alone but always by regularity, there will in the future not be enough room in the air for indiscriminate flying in all directions and therefore flying must be confined to routes.

By confining aircraft to routes one can establish one's ground facilities in a better and more comprehensive manner, but what is far more important is that one can the more easily control aircraft and enable them to avoid collision by confining them to routes and causing them to follow those routes in a predetermined manner.

In presenting this theory I do not lose sight of the fact that several attempts have been made in the past, and no doubt more will be made in the future, to introduce a system of automatically indicating to one aircraft the presence, location, and even the bearing of another aircraft; but even if such a system was invented I am not convinced that, although it might be made subsidiary to the system of confining aircraft to routes, it can of itself solve the problem.

I am well aware that by confining aircraft to routes one is going to make it not impossible, but certainly difficult, for the private owner to fly as he wishes or rather as he does to-day, but as little as one desires to restrict his activities and his desire to fly where he wishes one must, I feel sure, consider his requirements only in relation to regular air transport craft to which priority must be given.

To those of you who are not acquainted with control of air traffic on busy and recognised routes, I think I should explain that this proposed method of confining aircraft to routes is not a theory but that which is done every day in bad weather on the Croydon-Continental route and one which has stood the test

of time. My theory that in the future all aircraft will have to be confined to fixed routes is nothing more or less than an extension of that existing practice.

If one accepts the principle of confining aircraft to routes the problem becomes one of controlling aircraft along an airway and then in the vicinity of an aerodrome.

When aircraft are following an airway it is not a difficult problem to keep them at a safe distance from one another by instructing them to fly at different heights. One must, of course, admit that even that method can, very largely due to the varying speed of aircraft, reach saturation point, but I think it will suffice for some time to come.

I assume there will be main routes and subsidiary routes, and both of those can be divided into two-way and one-way traffic routes.

One must remember that although one-way traffic seems a sensible cure for many of the dangers of collision, it is one of those principles which are excellent in theory, but as I can point out to you are, at least in our case, impossible in practice—certainly where it would be most useful if it was practicable.

The principle of one-way traffic is more applicable to aircraft in the vicinity of an aerodrome, therefore I will leave it till I come to that problem.

One should now suggest what aids and facilities are required to enable aircraft to follow fixed routes.

It will be apparent that the outstanding and most necessary aid for that purpose is wireless. Another very necessary aid for night use is that of light beacons. (It might seem unnecessary to call a beacon a light beacon, but it must be remembered we now have what have come to be known as radio beacons.)

The wireless facilities so far in use in this and other countries are mostly one of the direction-finding type.

That method of assisting an aircraft to follow a fixed route is excellent so far as it goes, but in spite of what any wireless expert might say, I cannot believe that it can be nearly as efficient as the radio beacon and particularly the visual directive type.

I lay emphasis on the visual type because we in this country (for which I must accept a large part of the blame, if blame is to be apportioned to anyone) have resolutely turned our faces against the aural type for the reason that at the very time when a pilot must be mentally alert it must at least tend to distract him to have a continual series of noises in one ear and then in the other. I think I might take this opportunity of explaining that it is because of our preference for the visual type of radio beacon that it took us some four years to develop the radio beacon now installed, but not yet in general operation at Croydon.

This visual and directive type of beacon can enable a machine to follow a route and to keep on its right side of the centre line of the route, and will from actual tests lead a machine very accurately to the aerodrome from a range of anything up to one hundred miles, but by itself it cannot do more.

As it is most necessary for a pilot to have indicated to him at fairly frequent intervals precisely where he is along that route as well as for him to be told to fly at a predetermined height, some other aid is required.

It is easy to imagine how completely any machine crossing such a route, and particularly one not equipped with wireless, can completely upset this organisation.

The method of indicating to a pilot precisely where he is along a route can and will be accomplished by the use of short range marker radio beacons, each of which will emit a different signal or at least will not be permitted to give the same signal within, say, one hundred miles of another along that or any other route.

Light beacons are used in the same manner as marker radio beacons, and although I have heard it suggested that they are thereby superfluous, I do not

agree with that contention. They form a very useful auxiliary to marker beacons and should any of the radio beacons fail can act at least at night time as a most useful substitute.

Provided aircraft are:—

(i) Confined to routes;
(ii) Are safely spaced along those routes; and
(iii) Fly at different heights,

I see no difficulty or cause for fearing collision.

But in the light of our present knowledge I see no other cure for that potential evil—collision.

I have so far dealt with the actual operation of the machine itself, but I have yet to suggest how that control will be exercised.

It may be looking some way ahead, but it rather seems that all routes will have to be divided into sections with a control officer in charge of each, much in the same way as a railway signalman controls his own section of the line, the difference being the length of section in the air route will be many times that of the railway line.

I am prepared to be told that such an idea is a fantastic one—perhaps it is for the present, but I see no other cure for the future.

Each control officer will, of necessity, have in front of him an indicator telling him precisely where each machine is and particularly its height along their own section of the route.

Where routes cross, as they must somewhere, the flat level-crossing as used by railways will be too dangerous for busy air routes, and there again arises the necessity for aircraft on different routes and on points where they cross to fly at different heights.

This method of confining aircraft to routes must however become complicated if one is going to insist on all aircraft of greatly varying speeds following the same route or if so at any height near to one another, therefore by the time we have the mail carrier and fast passenger aircraft flying at 500 m.p.h. and yet are obtaining useful service for carrying cargo from the old air tramp which might continue to fly at 200 to 300 m.p.h., we must consider either that these two classes fly on different routes or that possibly the fast machines will fly very high.

But, nevertheless, when we do reach such speeds it is going to be more necessary than ever to prevent indiscriminate flying and the natural corollary to indiscriminate flying is the confining of aircraft to routes.

The control of traffic on an airway is, however, not going to be nearly so difficult as the control of traffic in the vicinity of an aerodrome. It is at an aerodrome that aircraft converge and for that reason even to-day we have found it necessary to request certain aircraft to wait, or to use a nautical term to lay-off, until other machines have been helped in. I am here, of course, referring to flying in conditions of bad visibility.

It may be of interest to give here some indication of the difficulties we have had regarding the control of traffic in the vicinity of Croydon aerodrome and how we hope to combat those difficulties.

Croydon, of course, is cursed—I can use no other term—by having the range of hills rising to nearly 1,000ft. known as the North Downs, which hills act as a barrier to 50 per cent. of the continental aircraft using Croydon.

In bad weather the pilot has the choice of flying in or over the clouds above the hills and then has to come down through the clouds over a busy aerodrome, which can be most unpleasant.

His alternative is to follow the line of one of the valleys which penetrate this range of hills, and this of course is done regularly. That method of approach to Croydon for an incoming machine is all right until such time as an

outgoing machine happens to use the same valley at the same time. Aircraft have been known to pass one another in a valley, but it is no use denying that it is very dangerous and should not be allowed.

The most natural suggestion to make is why not use one valley for incoming machines and another for outgoing machines—in other words, institute one-way traffic. I made the same suggestion myself many years ago and it was only after much consideration did I admit that I was defeated.

The reason is that so often one valley is closed from a meteorological point of view and the other remains open and thereby is one's system of one-way traffic defeated—it happens to be one-way literally—either you stop all your outgoing or all your incoming traffic, and it would almost appear that to make matters more difficult nature so varies the meteorological conditions in each valley from time to time as to make it impossible to suggest any system of arranging for inward traffic to continue, say, for half an hour and then permit only outgoing traffic to use it.

In other words, one must permit both incoming and outgoing traffic to use the same valley, but yet one must devise some system of avoiding collision.

There is no doubt that flying up and down valleys is not an ideal way of flying, but until we reach a stage of insisting on all pilots flying blind, whereby outgoing traffic might climb up through the clouds and incoming traffic remain below them, at least in so far as Croydon is concerned, we must permit valley flying.

We have had as many as twenty machines at one time approaching and leaving Croydon and it is no easy matter to sort them out, and to complicate matters their direction of approach and departure is nearly always within an angle of 90°.

The method of controlling air traffic in the vicinity of Croydon, and which method we hope to be able to institute very shortly, is one known as "the controlled zone scheme."

Very briefly, the scheme is one whereby when visibility is reduced to the international fog standard—namely, 1,000 yards horizontally and 1,000ft. vertically—the controlled zone scheme will automatically come into force and all aircraft will, so far as is possible, be notified that the scheme is in force. It is considered justifiable to expect pilots of aircraft which cannot be told of the existence of the scheme to judge for themselves what the standard of visibility is and to act accordingly.

The zone is very approximately an area of ten miles around Croydon, and within that area aircraft will, during the operation of the scheme, be permitted to fly only with the permission of the control officer.

No attempt will be made to instruct aircraft to follow a certain route, but incoming aircraft will be permitted to follow a certain route only so long as they do not endanger any other machine, and failing their ability to do that will be ordered to lay-off the zone until such time as some route is permissible.

No outgoing aircraft will be permitted to depart except in such manner as to make it impossible to endanger any incoming machine.

You will note the significant difference that in this control of air traffic from the ground the control of outgoing aircraft, or perhaps one should say their departure, will be of very positive kind, but the control of incoming aircraft will be negative. No attempt will be made by the control officer to instruct an incoming machine in flight, that it must follow a particular route, but when necessary that machine will be told that it must *not* follow a particular route and it will be suggested that it should try some other means of approach.

It will be remembered that earlier on in this paper I suggested that priority must always be given to the aircraft in flight and that is why absolute control will be exercised over the departing aircraft, but not over the incoming machine.

With the assistance of the operating companies, all of whom have acquiesced

in the suggestion, we hope to institute this system very shortly on a voluntary basis and then to later establish it on a compulsory basis.

If it is necessary there appears to be no reason why the controlled zone scheme should not be in force at any busy aerodrome, but it is particularly necessary at Croydon, due to the physical features of the surrounding country.

The actual method of approach to the aerodrome is covered by the existing international regulations, and those regulations having stood the test of time might well be adhered to.

It might be relevant here to make a brief reference to what is being done in this country to assist aircraft to land " blind " or very nearly so. We have not yet reached the stage of its being necessary or even advisable for pilots to land aeroplanes absolutely blindly when they cannot see the colloquial yard ahead.

But we are already contending with the problem of having brought a pilot to the aerodrome of helping him to land in conditions of say two to three hundred yards visibility—that is when for practical purposes he cannot see any distance ahead, but can see enough of the ground below him to actually enable him to land.

That is the manner in which we are approaching the problem and we hope before very long at Croydon to be able to tell a pilot to approach on a certain bearing, to tell him at stated intervals how near he is horizontally to the landing areas and then leave it to him to actually land the machine. It may not sound very useful stated as briefly as this, but one must remember that the pilot will know that there is nothing in the air or on the ground which, once he has commenced to bring his machine in in that manner, will get in his way.

Having dealt with the control of traffic in the air, we now come to the comparatively simple problem of the control of traffic on the ground.

We have our international regulations for the control of traffic on the ground and although they could, I think, be slightly modified, the most necessary point at present is to enforce the existing regulations.

The regulation most necessary to be enforced is to cause all taxying aircraft to manœuvre only on the perimeter of the landing area, thereby leaving the landing area absolutely clear for aircraft landing and taking off.

One must, of course, lay down a proper path around the landing area for taxying, but whether operating companies do or do not say they cannot afford to taxi, so far I am convinced that it is in their own interests to adopt this method, certainly at aerodromes where one has aircraft arriving and departing every few minutes.

I have no hesitation in saying that the taxying paths and aerodrome control exercised at the famous Berlin Tempelhof Aerodrome are ideal. They would, of course, have to be adapted to meet local conditions, but it is the principle which is so sound.

Instead of the eleventh commandment being what it is to-day I should like to see substituted for it, " Thou shalt not taxi across the landing area."

That certainly is the regulation which it is most necessary to enforce to-day.

In the time at my disposal I have referred to control both in the air and on the ground.

I have not endeavoured to suggest any detail method of control but rather to consider only the principles involved.

In conclusion, I must add that these views which I have put before you are my personal ones.

Discussion

Major R. H. Mayo, F.R.Ae.S.: There was a good deal of discussion going on about the control of civil flying, and there might be some attending the meeting who felt that there was a good deal too much control at the present time. Possibly those views would find expression before a certain committee which, it

was understood, was to get to work before long. But whatever the views might be about the control of flying in general and in regard to the regulation of the airworthiness of civil aircraft, and so on, he felt sure all would agree that a wide measure of official control of air ports and air routes was a necessity. Everyone would agree, too, that the British Directorate of Civil Aviation had exercised its authority wisely and efficiently, and that it had done everything it could to develop an adequate system of control over the air routes, particularly those emanating from Croydon, and to foresee the developments which were likely to take place in the future. He congratulated Major Mealing on the very active work that he had done with those objects in view.

He was glad to note the emphasis which Major Mealing had laid upon the risk of collision, for that, he thought, would be the most serious risk in commercial and civil aviation in the future. It might be presumed that the numbers of civil aircraft flying would increase very greatly, and unless the problem of reducing the risks of collision was tackled very seriously it was quite obvious that general flying would have to be seriously restricted. He did not think he could usefully comment on Major Mealing's remarks as to the steps that were being taken to institute a system of control of traffic on the regular air routes; but it did appear that something more might be done, and would have to be done, about the regulation of aircraft design and equipment in relation to the collision risk. Some people took the view that official control of the general airworthiness of private aircraft was not essential; if any aircraft was produced which was not really airworthy it would very quickly "die a natural death." But there was room for regulation by a responsible authority in regard to that vitally important question of the view provided for the pilot and the crew. He had seen and flown many aircraft which were not provided with a really adequate view from the pilot's seat; that matter was apt to be overlooked, even though it constituted a serious danger to the occupants of the aircraft and just as serious a danger to those of other aircraft. It was altogether wrong that commercial and private aircraft, the regular air liners and "law-abiding" aircraft of the smaller kinds, should be subjected to the risk of collision (which had mutually disastrous results to both aircraft involved), through allowing aircraft which did not provide an adequate view for the pilot to take the air. He, personally, would not regret a considerable tightening up of regulations in that respect.

There might be more regulation also in regard to the equipment of aircraft, at least of such aircraft as were liable to be operated on or near regular routes. It seemed that traffic was already becoming so congested on the main continental routes that the time had arrived when aircraft not equipped with wireless should be prohibited from flying over those routes. That might sound a little drastic, and it would need rather careful interpretation, but there should be a general regulation to keep the routes clear of aircraft which were not equipped to receive important signals sent out by the controlling aerodromes.

It seemed to him that the risk of collision was often increased by aircraft having to make a circuit of the aerodrome before landing; that seemed to him to be sometimes a definitely unsound practice. He quite agreed that it had to be done unless equipment was provided to warn a pilot as to what the position was, but it did appear that a great deal more could be done in the way of sending signals from the ground to the aircraft to enable a pilot to fly straight in and land without any circling, thus eliminating waste of petrol and reducing the risk of collision with other aircraft using the aerodrome. In this connection he recalled that at Miami, Florida, last year, he had seen an interesting signalling device, used by Pan American Airways at their land airport. The device consisted merely of a pair of red and green lights mounted on gimbals, so that one or other of the lights could be directed at the incoming aircraft. If the aerodrome was clear there was no objection to landing straight into the wind, the green light was directed at the aircraft and the pilot could not fail to pick it up. If the

aerodrome was not clear the red light was directed to the incoming aircraft, which would then make a circuit in the ordinary way. It was found in practice that in the large majority of cases it was possible to give the incoming aircraft the green signal. Major Mayo agreed that that particular form of signal could not always be applied in bad weather, but he thought it could be developed and usefully employed to a great extent, and that at the same time other forms of signalling could be developed for bad weather conditions.

Mr. C. G. GREY (Editor of *The Aeroplane*): He remarked that in accord with custom he wished to congratulate Major Mealing on having delivered quite the best lecture on Civil Aviation ever delivered in that hall. Hitherto those who had had dealings with Major Mealing had regarded him as one of the most human and humane of Government officials. But his proposal that in future civil aeroplanes of all kinds should be strictly confined, under pains and penalties which could be inflicted by the Air Ministry, to certain stated routes, seemed to represent the quintessence of inhumanity. Could one imagine a whole party who had been doing themselves well at some future *Bienvenue Aérienne* in France, streaming home along the air route, possibly a little doubtful about what their wireless receivers were telling them and not by any means sure of what their instruments were reading, getting mixed up with air-liners all the way along? He had not realised before that Major Mealing's first name was Mussolini.

Captain IVOR MCCLURE: It seemed that Major Mealing had sounded the death knell of private flying, by the proposals made in the paper. Private flying would be practically impossible when commercial aviation had developed into a paying concern. Commercial machines, in order to pay, would have to fly with 100 per cent. regularity. More time and money would have to be devoted to the study of flying in conditions of low visibility which prevented the movement of other forms of transport. If there were a fog which reduced visibility to three or four yards, the machines would have to be flown by instruments, and this would call for a considerable degree of skill and practice on the part of the pilots, who, presumably, would be furnished by the Air Ministry with special licences. Anyone who did not possess such a licence would not be able to fly on these controlled routes, on which there would be a considerable number of aircraft. Thus, private aviators would be able to fly only in good weather and in the spaces between the controlled routes. Who would spend money on an aeroplane if he could fly it only on certain days and then only around his back yard?

Mr. JACKAMAN: Had Major Mealing any views concerning the vertical beam which was used so much in America to bring aircraft straight into an aerodrome? He believed that when an aircraft was brought to the precincts of the aerodrome by means of the ordinary lateral or directional beam it was assisted by the vertical beam; when the light warned the pilot that he was on the vertical beam he just flattened out and landed.

Commenting on the fear expressed, that the adoption of the proposals in the paper would involve the stoppage of private flying, Mr. Jackaman said he gathered that Major Mealing, in making those proposals, was concerned mainly with the fairly distant future, and that, so far as they related to the present, he had in mind a restriction only in respect of the main continental routes, such as London-Paris, London-Berlin, and so on. Would it not be practicable, he asked, on such days as it was possible for private aviators to fly at all, for them to be sent to Gravesend, or Heston, or other aerodrome, and to be told there that they must follow direct routes, whilst the air liners would stick to their ordinary directional wireless routes?

Discussing light beacons for use at night, he said that on quite a number of occasions he had flown to Paris and back at night in a machine not fitted with wireless, and under those circumstances such beacons were invaluable, particu-

larly when the wind had changed during the journey, either when crossing the Channel or even between Paris and the coast. In a machine fitted with wireless one did not need the light beacons, because one could follow the route by means of the directions received from the aerodrome. He asked if Major Mealing had in mind light beacons entirely for the direction of machines without wireless, and, if so, whether it was right that machines without wireless should be allowed to fly at night on the international routes.

Finally, he asked why red neon lights were used, because, although red was supposed to penetrate fog, it definitely did not penetrate white fog or mist or low cloud, and at night he had seen the flood light on the ground two, or three, or four minutes before he had seen the red neon beacon. Recently a green light had been installed at Heston, and it seemed to him that that was the right coloured light to use, at any rate at night time. When leaving London one could see the row of green lights in the Cricklewood direction better than one could see red lights.

Captain R. C. PRESTON, A.F.R.Ae.S.: On occasions of really bad weather—the only occasions on which there was grave risk of collision—the onus of avoiding congestion around a big terminal airport like Croydon should rest with the people best equipped to cope with abnormal situations. Therefore, the converse of the suggestion by a previous speaker would apply—namely, instead of private flying being interfered with, the big operating companies should be instructed to use the alternative aerodromes. This would at least help to eliminate existing dangers to heavy passenger-carrying aircraft.

On the other hand, he realised that this did not solve the problem of air traffic control, since proper control implied ability to deal with any abnormal situation without causing dislocation.

Then surely, if the problem is as serious as it is alleged to be, the only alternative is to forbid any private comings and goings within a specified distance of the airport and reserve Croydon, or its equivalent in any other city, for radio-fitted aircraft only.

Mr. Nigel Norman, he understood, once expressed the principle that as visual control from the ground to an aircraft in the air is almost impossible to achieve, any form of control should be confined to aircraft on the ground only. If that held good, surely there would always be a danger of collision so long as free lance flying by all and sundry—ignorant and careless of times of arrival and departure of air liners—was allowed to continue around a big terminal airport under conditions of poor visibility.

Mr. BRIE: It was amazing how any new suggestion aroused criticism; obviously, the suggestions made by Major Mealing related to the future. With regard to the statement in the paper that the main difference between surface and air transport was the inability of aeroplanes to remain stationary, Mr. Brie pointed out that if they had aircraft which could remain stationary, then obviously the proposals which, it was said, would definitely hinder the development of civil aviation would not be necessary. He, personally, believed that long before such regulations came into force they would have aircraft which could remain stationary in the air.

Mr. W. O. MANNING, F.R.Ae.S.: He questioned the necessity for closing the air routes to private aeroplanes. In support of his contention he pointed out that they had a more or less analogous situation on the roads, there being a large number of small privately-owned cars and a few motor coaches, but they did not ask the police to ensure that the small cars did not interfere with the motor coaches. He considered that the air, like the roads, should be free for all traffic.

Mr. R. H. EVANS: Referring to Major Mealing's suggestion that at some time in the future all routes would have to be divided into sections, with a control officer in charge of each, much in the same way as a railway signalman controls his own section of the line, he asked what training he would consider necessary

for these control officers. He pointed out that control officers such as those of the Trinity Brethren were highly-paid men; those who started in the lower grade would not reach the position of control officers until after 15 years' service, and those who started in the higher grade, *i.e.*, public school or university men, probably would not reach that position in less than eight years. It would also appear that if the control suggested were effective it would surely force all private owners to fit their aircraft with wireless.

Captain G. F. MEAGER, A.F.R.Ae.S.: He supposed that the suggested route system would apply only to short routes overland. He did not see how it could apply to long-distance oversea routes, because the course followed by an aeroplane flying long distances oversea would depend upon the weather reports received from time to time.

On thinking over Major Mealing's scheme for confining all aircraft to certain specified routes, it would be interesting to know how this is going to be carried out in practice even on the short routes at present in operation. By routes he presumed the lecturer referred to different height levels as much as to different bearings.

It is certainly an excellent scheme, and much more practicable, to control the area within, say, a radius of ten miles or so of the terminal station, and this or a little more will probably turn out to be about the limit of effectual control. A pilot can be instructed to fly at a certain height or on a particular bearing, but who is to see that he keeps to this if in his opinion circumstances warrant his deviating from it? Are they to have a horde of aerial police to keep machines to their allotted routes, or is this control to be carried out by means of wireless beams, or merely by the goodwill and discipline of the pilots concerned?

It is a very difficult problem, but might he suggest that one means of easing the situation somewhat would be by decentralising a little by increasing the number of terminal aerodromes around London. For instance, Croydon might be used as the air head for traffic between England and France; Romford for German traffic; Gravesend, Holland; Heston or Hendon, West of England, and so on, all of course with local control in force. In fact these termini might even be used as arrival and departure platforms. Aerodromes in the centre of London as well as those around the outskirts would also tend to relieve the (anticipated) congestion.

To carry out the suggested control along entire routes with the present system of all traffic (goods and passenger) using the same terminal points would seem to him only possible if there were an International Board of Control which would take over the whole of the European air traffic and thus have the entire system under unified control and discipline. He supposed this was too much an idea of the future to be a practical argument to-day.

Captain G. P. OLLEY: It was gratifying to pilots using the recognised air routes to know that Major Mealing and the Air Ministry were giving so much attention to the control of civil aircraft in the air, especially on those recognised routes. A risk which was not mentioned in the paper, however, was the risk of collision from the rear, so that in considering the control of aircraft, especially in bad weather, on recognised routes, height was of great importance. In this connection he pointed out that private owners, who might not have wireless installations and other instruments necessary for blind flying, were usually forced down by bad weather, or very bad weather, and they usually flew below the clouds, whereas the big machines on the air routes flew either in or above the clouds. It would be a pity if private owners were forced out of the sky.

Wing Commander ALLEN: He did not quite see eye to eye with Major Mealing concerning the question of control. Perhaps he had gained a wrong impression of some of the statements in the paper, but he did not think it was necessary at all times to keep private aircraft not fitted with wireless entirely off the recognised air routes by regulation. Focal areas under conditions of bad

visibility were another matter. Nevertheless, just as a yachtsman in a small yacht would not deliberately place himself in the line of fast moving sea traffic, so the owner of an aeroplane (not fitted with wireless) for his own security would, under conditions of bad visibility, keep off the usual track of air liners. Aircraft fitted with wireless and in consequence with the help of the D.F. organisation at their disposal would tend to fly oblivious of cloud at a greater height leaving the vicinity of the ground free for machines not so equipped.

Discussing the control of aircraft on the ground, Wing Commander Allen said he did not take kindly to the perimeter rule. It was rather contrary to human nature to take an aircraft all round the aerodrome after landing it and before coming up to the arrival point on the aerodrome. A simple way out of the difficulty, he suggested, was to make a rule that all machines must land on the right of any machine that had already landed, and that when once a machine had landed it must turn left only. That rule was applied in the Indian Command when he was there, and more than once he had seen as many as four squadrons, comprising some 36 machines, landing at 20-second intervals. The method was quite easy and quite safe.

There were certain rules of the air which could with advantage be modified. For example, the crossing rule provided tremendous food for thought. It had been agreed that the pilot, if he did not sit on the longitudinal axis of the aircraft should sit on the left-hand side; yet he had to look out for machines on the right-hand side. That was worth thinking about. Inasmuch as a pilot was sitting on the left, it seemed natural that he should land on the right of any machine which had landed before his, because he could keep in view all the time any machines on his left. Wing Commander Allen was in complete agreement with Major Mayo concerning the tremendous importance of ensuring good visibility from the pilot's seat. He also considered it unnecessary always to circle an aerodrome, and did not see why a green light should not be used to indicate to a pilot that he could fly straight in and land. The radio beacon was undoubtedly of tremendous help; it must be remembered, however, in this connection, that presumably a number of aircraft were being drawn into a cone, and it was at that point, *i.e.*, the meeting point, that the danger of congestion and collision was most likely to arise. It was extraordinarily difficult to legislate for what might be termed the focal areas.

At the present stage, however, one could not be dogmatic on these matters, and he submitted that any scheme of control that was put forward at present must be very much of a tentative nature; also, it must be more advisory and informative than regulative. Broadly speaking, he did not believe that the man on the ground would ever be able to control effectively the man in the air; the most that could be done by the man on the ground was to give information to the man in the air, to enable the latter to make a sound decision.

The CHAIRMAN: Would Major Mealing state in greater detail, in the light of his experience of watching air transport operations in this and other countries, how he would proceed if he had to lay down a system to-day for an airport where there was continuous traffic in and out both by day and by night, under the three conditions likely to be met with—normal clear weather conditions, thick weather (confining his remarks primarily to the condition when visibility was only about 300 or 400 yards), and night conditions? Particularly he asked Major Mealing to comment upon the method applied by Pan American Airways at Miami, *i.e.*, a method employing the use of a red and a green light mounted on gimbals.

There was no doubt that, as had already been stated, Major Mealing was a very pleasant official indeed to have dealings with; he was always willing to see anyone and to discuss these problems and listen to proposals, even though they might run counter to his own ideas, and he would give a reasoned argument as to the pros and cons. But the Chairman confessed that he had been a little startled by the proposal in the paper concerning confining aircraft to routes.

Major Mealing had stated that he was not going to propose anything of a very revolutionary character, and perhaps he did not mean all that had been read into his statements concerning the proposal. Probably he meant that aircraft other than the regular aircraft would have to be controlled only in the vicinity of the regular routes, and presumably he did not suggest that the operation of private aircraft should be controlled in every direction outside the routes followed by the regular aircraft.

Finally, in proposing a vote of thanks to Major Mealing for his paper, the Chairman expressed the hope that at some time in the future he would address the Society again on this matter of control, because it was one which was becoming increasingly important. A certain measure of control was necessary, but they did not want over-control.

Reply to Discussion

Replying first to the suggestion that it was unnecessary to circle round an aerodrome before landing, he reminded the meeting that circling was one of the international requirements drawn up some eleven years ago, it being provided that an aeroplane must make at least one complete circuit. The idea was that every pilot coming in to land should know which of those waiting to land had priority, *i.e.*, the lowest one. If, however, there could be devised a system of indicating to a particular machine that it could come straight in and land it would be excellent. But what would happen at a busy aerodrome, where there might be three, four, five, or six machines coming in within a very few minutes after each other? That density of traffic was being achieved to-day, and one could not say how far it would increase in the future. One could not pick out one machine and tell the pilot to land, at the same time signalling to the others to lay off; but even if they did lay off, were they to fly about indiscriminately? He did not suggest what was the answer. Perhaps one could best sum up the position by saying that if one could indicate to certain machines that they were to stay away for the time being and that they were not to manœuvre or make themselves a nuisance to anybody else, well and good.

Major Mayo: The system he had mentioned was one in which a positive signal was given to a particular machine that it could come in. Unless that signal was given it must follow the normal procedure which would apply if the system were not working, and no plane could land until the pilot had seen the green light which was positively directed at it.

Major Mealing: That simplified matters a good deal. He did not quite see that the proposal to confine aircraft to routes was tantamount to sounding the death knell of private flying. Again he emphasised that he was referring to the future. It could be contended that in keeping a non-wireless machine away from the wireless machine one was certainly making flying safer for the wireless machine; in doing that, was not one making it safer also for the non-wireless machine? A collision was a calamity for both machines involved, and the matter must be regarded from that point of view. Unfortunately, one had to discriminate as to which machine should have priority. He had not intended to convey that all aircraft to-day must always follow defined routes, but certainly they should in bad weather. At the same time, he believed that in the future aircraft would travel at very high speeds, amounting to several hundred miles per hour, and he was not at all certain that one should not anticipate a time when all aircraft must follow routes. Would it really be safe to have any kind of machine flying here, there and everywhere? Surely it was much safer to stick to certain directions! His proposal did not sound the death knell of private flying for the time being, at any rate. The Air Ministry, however, whilst keeping in mind always how much the private owner had done for the country—and, after all, private owners had done more in this country than anywhere else in the world—must give priority to the regular transport machines and help them through.

He gathered that Mr. Jackaman, when referring to the vertical beam, meant the American experiment in which machines landed down a curved beam, which experiment had been carried out at Newark Aerodrome, in America, on several occasions. It had been carried out principally by Dolittle, under a hood and in fog. According to the latest information, the scheme was an excellent one from the experimental point of view, and from the Service (military) point of view it was quite a good scheme to carry on with, but Major Mealing was by no means satisfied that it was yet safe to bring down a passenger-carrying machine in that way.

When the authorities in this country were tackling recently the problem of landing in fog, they had to make up their minds whether they would straight away contend with the problem of actually landing the machine or merely to assist the machine to the landing area and then on the assumption that he can see sufficient of the ground below him leave the pilot to land unaided.

It must be remembered that by means of wireless and pyrotechnics it is possible to bring a machine over the aerodrome at Croydon to-day, but repeatedly one can hear the machine from the control tower, but one cannot see it. Pilots can do that because they know every chimney pot and blade of grass around the aerodrome.

The initial equipment which was being experimented with gave the pilot the bearing on which to come in, told him how near he was to the aerodrome, and when he was quite near the ground he could see sufficient of it to be able to land his machine; but all the time he knew that there was nothing in front of him. We had not yet reached the point of experimenting with the vertical or curved beam, *i.e.*, really blind landing.

The suggestion made by Mr. Jackaman, that private owners should be sent to various aerodromes in order to be told the routes they should follow, seemed an excellent one and was worth following up. If we could spread out the traffic in some predetermined manner it would certainly assist. The Air Ministry was still trying to settle the problem as to whether machines without wireless should be allowed to follow the regular routes. It was so easy to be dogmatic and to rule that they must not follow such routes; but one could not do that, for it was tantamount to prohibiting private flying. At the same time, if it were ruled that all machines must be fitted with wireless we could help them very little now, although in the future perhaps we should be able to help them quite a lot. If we were thinking in terms of preventing collisions, the help they required was knowledge of the whereabouts of other machines. If a machine had a receiving set it could receive indications, but it was going to be difficult, if not impossible, to permit private owners to have transmitting sets. If the authorities could be convinced that a transmitting set would enable a private owner reasonably and safely to follow pre-defined routes they would consider the suggestion, but so far they could not see that a transmitter set on a private machine would help; at least, with the present system of wireless stations. Whether that problem would be simplified in the future, when there were more wireless stations, he did not know.

The reason why red was chosen as the colour for the aerodrome beacon was that from every point of view it was the best light in a fog; red had greater power than any other colour to penetrate a fog. As to Mr. Jackaman's suggestion that green lights at Hendon were more clearly and easily distinguishable than any other lights, Major Mealing said that he personally had not seen them, but he believed there was an explanation. At the time when red was chosen as the colour for aerodrome beacons there were not nearly so many red neon signs on picture houses and other buildings as there are to-day; when coming out towards Hanworth and Heston one saw a great deal of red lighting, and it was confusing. However, provided that a red aerodrome beacon was given a distinctive character it could be picked out more easily than any other colour.

Perhaps he had made a bad slip when he had referred to aircraft being unable to remain still in the air; he had not seen Captain Brie present when he had made that remark.

The answer to Mr. Manning's question as to why the regular air traffic should have priority was to be found by reference to shipping, because shipping on main routes always had priority over small privately-owned craft.

Mr. MANNING: He understood that in all cases the steamship had to give way to the sailing ship.

Major MEALING: Replying to the question as to the standard to be attained by the officers controlling sections of air routes as suggested in the paper, he could not suggest a better standard than that of the present Aerodrome Control Officer at Croydon. His qualifications included a knowledge of piloting, navigation, air legislation and everything else that appeared to be necessary to enable him to ensure safety. Certainly control officers must be very highly trained. It must not be thought that anybody would be able to do the job automatically, because experience at Croydon had shown that control of air traffic, even to-day, was not automatic, and we would not suggest that it ever would be automatic. No matter what regulations or rules were laid down, one would from time to time come up against problems for which there were no rules; therefore, it was always necessary to have a highly qualified officer in control.

It was rather difficult to visualise whether in future the overland or oversea routes would predominate, and even to-day he would not like to say what was the percentage of either to the total.

With regard to the Chairman's request for further views concerning the control of air traffic at a busy aerodrome in clear weather, bad weather and at night, he said that so far as clear weather conditions were concerned, provided certain *simple* regulations were adhered to, so that each pilot knew exactly what others would do, there should be no difficulty, and very little regulation was necessary. He emphasised simplicity. With regard to bad weather, the international definition of " fog " was not such as the London " pea-soup " fog; it meant bad visibility. In conditions of bad visibility there must be such control as would bring aircraft safely into and get it safely away from an aerodrome. It was necessary to keep incoming aircraft to one route and outgoing aircraft to another; provided outgoing aircraft flew straight away from the aerodrome and did not turn until they had travelled a certain distance from it, no matter what route they wished to follow, operations should be fairly simple. For night flying one might almost suggest that the requirements were the same as those for bad weather, except that one must admit that at present the navigation lights on aircraft were very bad; indeed, he knew of only one particular light which really complied with international requirements so far as range of light was concerned. If one could ensure proper lighting on aircraft it seemed that the regulations at airports could be as simple as those required for fair weather; but under present circumstances he suggested that we must apply the bad weather regulations. A pilot in a machine could see very little more of another machine by night under present conditions than he could see during the daytime when visibility was bad.

ABSTRACTS AND NOTICES

FROM THE

SCIENTIFIC AND TECHNICAL PRESS

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry

(*Prepared by R.T.P.*)

No. 28. OCTOBER, 1933

LIST OF ABBREVIATIONS OF TITLES OF JOURNALS.

Aeron. Eng.	Aeronautical Engineering.
Airc. Eng.	Aircraft Engineering.
Ann. d. Phys.	Annalen der Physik (Germany), Annales de Physique (France).
Army Ord.	Army Ordinance.
Autom. Absts.	Automotive Abstracts.
Autom. Tech. Zeit.	Automobiltechnische Zeitschrift.
Autom. Eng.	Automobile Engineer.
Autom. Ind.	Automotive Industries.
Bell Tele.	Bell Telephone Laboratory.
Bur. Stan. J. Res.	Bureau of Standards (U.S.A.) Journal of Research.
Chem. Absts.	Chemical Abstracts.
Chem. and Ind.	Chemistry and Industry.
F.G.I.	Forschung auf dem Debiete des Ingenieurwesens.
Fuel.	Fuel in Science and Practice.
H.F. Technik.	Hochfrequenztechnik und Electroakustik.
Ind. and Eng. Chem.	Industrial and Engineering Chemistry.
J.R. Aer. Soc.	Journal of Royal Aeronautical Society.
J. Sci. Inst.	Journal of Scientific Instruments.
L'Aéron.	L'Aéronautique.
L.F.F.	Luftfahrtforschung.
N.A.C.A.	National Advisory Committee for Aeronautics (U.S.A.)
Phil. Mag.	Philosophical Magazine.
Phys. Rev.	Physical Review.
Phys. Zeit.	Physikalische Zeitschrift.
Proc. Inst. Rad. Eng.	Proceedings of the Institute of Radio Engineers.
Proc. Roy. Soc.	Proceedings of Royal Society.
Pub. Sc. et Tech.	Publications Scientifiques et Techniques du Ministère de l'Air.
Rev. S.G.A.	Revue de la Societé Générale Aéronautique.
Rev. F. Aer.	Revue des Forces Aériennes.
Rev. Sci. Insts.	Review of Scientific Instruments.

Riv. Aeron.	Rivista Aeronautica.
S.A.E. Jrnl.	Society of Automotive Engineers Journal.
Sci. Am.	Scientific American.
Tech. Aeron.	La Technique Aéronautique.
Z.A.M.M.	Zeitschrift für Angewandte Mathematik und Meckanik.
Z.F.M.	Zeitschrift für Flugtechnik und Motorluftschiffahrt.
Z. Instrum.	Zeitschrift für Instrumentenkunde.
Z. Metallk.	Zeitschrift für Metallkunde.
Z.V.D.I.	Zeitschrift für Vereines Deutscher Ingenieure.

Aircraft Design, etc.

Profile Characteristics at Super Sonic Velocities. (A. Busemann and O. Walchner, Forschung, Vol. 4, No. 2, March/April, 1933, pp. 87-92.) (5.102/26501 Germany.)

A description of the Göttingen wind channel for high velocities is illustrated by three section sketches. The selected aerofoil profiles were three Göttingen airscrew profiles Nos. 622, 623 and 624; three plano-convex, one symmetrical bi-convex, a wedge and a wedge with cylindrical nose. The polar diagrams are shown graphically for wind velocities about 1½ the speed of sound. The airscrew profiles show lower resistances with the sharp edge leading.

It is remarked that, by a very fortunate chance, an approximate physical treatment can be based on the hydrodynamical theory of an inviscid fluid, at least for certain types of suitable profiles with sharp leading and trailing edges, at which the velocity never falls below the speed of sound.

The analytical development appears to be based on an empirical modification of previous work by Ackeret, and it is difficult to assess the significance of the fairly close fit with experimental results for the plano-convex profiles.

For the wedge profiles, both observed and calculated, polar curves have a parabolic form but the numerical values are in the ratio of 5 : 1 at zero incidence.

Ceiling and Performance. (C. W. Tinson, Flight, Vol. 24, No. 53, 29/12/32, pp. 1232 f-g; Vol. 25, No. 4, 26/1/33, pp. 80 f-g; Vol. 25, No. 8, 23/2/33, pp. 178 a-d.) (5.106/26502 Great Britain.)

Empirical and semi-empirical formula for climbs, speed, and ceiling are plotted as families of curves for different parameters.

Ocean Air Transport. (Sci. Am., Vol. 148, No. 3, March, 1933, pp. 166-168.) (5.14/26503 U.S.A.)

Reference is made to the somewhat pessimistic views expressed by Dr. Kimball, of U.S. Weather Bureau, on ocean hazards, particularly fog.

The Dept. of Commerce lay down stringent regulations with regard to navigational equipment, and ability to navigate by instruments only.

Some details are given of flying boats operating on U.S.A. cross-sea air routes.

Civil Aviation. (Aviation, Vol. 32, No. 3, March, 1933, pp. 69-88.) (5.14/26504 U.S.A.)

A summary of aeronautical activities is given for U.S.A. in comparison with European countries and includes costs, air mails, factory output, training of pilots, and passenger miles. The totals show 1,200 airports and 20,000 miles of airways, and 140,000,000 passenger miles in 1932.

Reference is made to reductions in money available for army, navy and civil aviation.

Civil Aviation. (Autom. Ind., Vol. 68, No. 8, 25/2/33, pp. 256-261.) (5.14/26505 U.S.A.)

A list of 344 aeroplanes and 90 engines is given with specifications of type, dimensions, weights and performance.

Recent Methods in Riveting in Aircraft Construction. (Outside Germany.) (W. Pleines, Z.F.M., Vol. 24, No. 3, 14/2/33, pp. 65-75.) (5.16/26506 Germany.)

The article deals with the De Bergne process of riveting, in which the material is recessed in the neighbourhood of the rivet so as to reduce stressing in the latter.

Nine references (English and American).

Maintenance of Metal Air Frames. (S. G. Young, Airc. Eng., Vol. 5, No. 47, Jan., 1933, pp. 13 and 16.) (5.16/26507 Great Britain.)

Practical information is given for inspectors and air mechanics.

Welding, pinned sockets and riveting are discussed from the point of view of possible defects, and methods of inspection with a view to discovery.

The presence of inspectors' stamps or of rough file marks may be definitely dangerous, and smooth finish is desirable in modern high duty materials.

The finish and fit of rivets, screw bolts, and pins present points of importance.

Corrosion in inaccessible positions is a source of special difficulty, and protective coatings must be applied with extreme thoroughness.

Welding and heat treatment are sources of danger from corrosion in stainless and high tensile steels.

Strength of Stiffening Ribs. (A. Thum and S. Berg, Z.V.D.I., Vol. 77, No. 11, 18/3/33, pp. 281-287.) (5.25/26508 Germany.)

Plate sections are shown with stiffening ribs of various dimensions.

Expressions are given for relations between volume, loading, strain, deflection, etc., and a large number of graphical charts show the distribution of stress and the strength under steady load and impact.

Six references.

Rolling, Yawing and Hinge Moments on Rectangular Ailerons. (R. H. Heald, N.A.C.A. Tech. Note 441.) (5.30/26509 U.S.A.)

Empirical expressions are formed with the dimensions of the ailerons, the angular displacement and the distance from the rolling and yawing axes of the aeroplane as parameters.

These are shown graphically in five diagrams in comparison with experimental points from three previous technical notes.

Observed values of moments produced by pairs of ailerons are found to agree closely with the sums of the moments of the ailerons observed separately.

Six references.

Further English Investigation on Forced Vibrations in the Tail Structure. (H. Blenk, Z.F.M., Vol. 24, No. 1, 14/1/33, pp. 21-24. Appendix to D.V.L. Report 267.) (5.32/26510 Germany.)

By reason of the almost simultaneous appearance of the English and German reports on the Meopham accident (D.V.L. No. 267 and R. & M. 1360) no comparison of test results was made in either report. A summary is therefore given for information of German readers of the more recent R. & M. 1457.

Investigations on Elimination of Tail Flutter. (C. Biechteler, Z.F.M., Vol. 24, No. 1, 14/1/33, pp. 15-21. D.V.L. Report No. 309.) (5.32/26511 Germany.)

Reference is made to a qualitative investigation by G. Mathias in an unpublished D.V.L. report on a Junkers monoplane, and to Blenk, Hertel and Thalau's D.V.L. Report No. 267 on the German investigation into the Meopham accident.

In the present report full scale investigation was made on a B.F.W.-M. monoplane of similar general design.

The principal dimensions are specified and eight photographs show the complete aeroplane, the junction of wings and bodies, the skeletons of several fairings investigated, and the smooth streaming or variable fluttering of short yarn streamers distributed over the wings to indicate smooth or disturbed flow over the wings.

Diagrams show the region of breakdown of smooth flow, with engine on or off and with or without fairing. Curves show the corresponding effect on the lift-incidence curve.

No evidence was found of forced vibrations in the tail under the different conditions investigated, with the exception of a slight shudder in side slip with engine off.

Aircraft—Landing Gear

Retractable Landing Gears. (R. M. Mock, Aviation, Vol. 32, No. 2, February, 1933, pp. 33-37.) (5.555/26512 U.S.A.)

Numerical estimates are given of the relative advantage of reduced head resistance as against the disadvantages of greater weight and complication.

An illustrative flying cost schedule is worked out on U.S.A. post office data and appears to be in favour of the retractable carriage.

The argument includes the increased risk of accident from failure of the retractable gear in reverse to restore the landing gear to its landing position.

Several types are discussed and illustrated by four photographs and four sketches of details.

Retractable Carriage. (U.S. Air Services, Vol. 18, No. 3, March, 1933, p. 23.) (5.555/26513 U.S.A.)

A photograph shows a new Martin monoplane bomber in flight with retracted carriage. The flying speed is stated to be 213 m.p.h.

Design of Twin Seaplane Floats. (H. Parkinson, Flight, Vol. 25, No. 8, 23/2/33, pp. 187 d-f.) (5.56/26514 Great Britain.)

Formulæ of reduction are given for determining the dimensions and scantling of floats similar to those used on the Schneider Cup winning seaplane.

Airscrews

Controlled Pitch Airscrew. (U.S. Air Services, Vol. 18, No. 3, March, 1933, pp. 27-30.) (5.658/26515 U.S.A.)

Descriptive technical details are given of the Hamilton hub. A photograph shows the airscrew and hub fitted to an aeroplane.

Four sketches illustrate the mechanical parts. The control is operated by oil pressure.

Graphical Functions for Calculating Performance of Heavily Loaded Marine Screws. (H. Lerbs, Werft-Reederei-Hafen, No. 3, 1/2/33, pp. 29-31.) (5.60/26516 Germany.)

The method of calculating airscrew performance by integrating over blade elements is applied to marine screws.

Goldstein's results for the induced velocity of trailing spiral vortices is used in Helmbold's form, and experimental corrections are applied in developing semi-empirical formulæ.

Numerical values of the functions are tabulated and plotted graphically for use in design.

Experimental values of r.p.m. and ship's speed were slightly in excess of the calculated values.

Five references.

Calibration of Windmill Anemometers at Low Speeds. (R. Loewenstein, Z.V.D.I., Vol. 77, No. 7, 18/2/33, pp. 177-178.) 5.670/26517 Germany.)

Reference is made to the difficulties inherent in low speed tests, in particular the induced wind. A description is given of a vertical shaft, up and down which the anemometer with a counterbalance weight is drawn at a known pace. The mean is taken as the true calibration curve.

Two examples are shown graphically in comparison with calibration in a jet of air from a nozzle.

Instruments

A New Precision Balance for Very Small Weights. (W. Loebe, Z. Instrum., No. 1, Jan., 1933, pp. 21-27.) (6.00/26518 Germany.)

The balance calibrated for weights between one and five milligrams has no jewelled pivots, the beam being suspended at each end on springs of such shape that a rotation of the beam does not alter its position in space appreciably.

The apparatus is cheap and robust.

Short Time Measurements in Engineering. (W. Ende, Z.V.D.I., Vol. 77, No. 1, 7/1/33, pp. 10-12.) (6.3/26519 Germany.)

The A.E.G. have developed a film camera capable of taking 80,000 pictures per second. The film speed is of the order of 20 m./sec. Two seconds are required to get the camera up to speed and the film is blank for 40 m., after which it is re-sensitised for 1-2 m. The saving in material is considerable, but accurate synchronisation is required. A few examples of film photographs are reproduced.

Nine references.

Three Co-ordinate Vibrograph. (J. E. Schrader, J. Frank. Inst., Vol. 215, No. 4, April, 1933, pp. 455-469.) (6.48/5.17/26520 U.S.A.)

A technical description of the apparatus is illustrated by photographs and diagrammatic sketches.

The instrument records linear acceleration in three rectangular co-ordinate directions continuously on a steadily moving film.

Fourteen sections of oscillogram are reproduced and illustrate records with vibrations with components in one only, in two, and in all three directions.

Illumination of Thermometer Mercury Thread by Reflected Red Light. (Z.V.D.I., Vol. 77, No. 2, 14/1/33, p. 47.) (6.71/26521 Germany.)

Light reflected from a polished strip of red enamel fused into the glass thermometer tube renders the mercury easily visible as a thick red column. A diagrammatic sectional sketch shows details of construction.

Reference Tables for Platinum Rhodium Thermocouples. (W. F. Roeser and H. T. Wensel, Bur. Stan. J. Res., Vol. 10, No. 2, Feb., 1933, pp. 275-287.) (6.71/26522 U.S.A.)

Twenty standard thermocouples were calibrated by comparison with platinum resistance thermometer and optical pyrometer and checked at the melting point of Zn, Sb, Ag, Au, Ni and Pt.

Empirical curves were constructed for seven temperature ranges and used for interpolation and extrapolation and the whole co-ordinated with the international temperature scale.

Thermo-Electric Properties of Platinum Rhodium Alloys. (F. R. Caldwell, Bur. Stan. J. Res., Vol. 10, No. 3, March, 1933, pp. 373-380.) (6.71/26523 U.S.A.)

The specimens contained a proportion of rhodium varying from 1/10 to 100 per cent.

The thermal e.m.f.'s against pure platinum were determined from 0°C. to 1,200°C. and the results are tabulated and shown graphically.

The results are in close agreement with other investigations.

Zeiss Inspection Equipment. (Autom. Eng., Vol. 23, No. 304, March, 1933, pp. 89-92.) (6.85/26524 Great Britain.)

Applications of the microscope to precision inspection are described. Errors in shape, defects in surface finish, profiles of gear teeth, etc., are observed with extreme accuracy.

Practical mountings for inspection are illustrated by photographs.

Stress Optical Experiments on Drilled Plates. (A. Hennig, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 53-63.) (6.86/26525 Germany.)

Optical glass is considered as the most suitable material on account of its freedom from internal stresses when suitably prepared. Reference is made to Report No. 34 of 1930, of the Munich Technical High School, details from which would be required to follow the present article fully.

The possibilities of conformal transformation are mentioned and reference is made to work by Filon.

An improbable elementary blunder by Coker is suggested but cannot be traced in the references given.

Approximate formulæ are quoted and contour diagrams of isoclinics and principal stresses show the effect of the ratio of diameter of hole to width of plate and of the application of force to the surface of the rivet-hole by the rivet at one or two symmetrical points.

The admirably finished contour drawings may suggest a greater accuracy than is attainable.

Twenty-two references.

Aircraft Flight

Estimation of (Aeroplane) Performance. (R. M. Clarkson, Aire. Eng., Vol. 5, No. 47, Jan., 1933, pp. 3-5; also Feb.-April.) (7.15/26526 Great Britain.)

The author gives a systematic scheme of reducing test figures to a standard basis by comparison. The results of modern aerodynamical theory are used, and empirical correction factors are given from experience. Expressions for aerodynamical qualities are defined and developed.

Engine output and efficiency are discussed as empirical functions of pressure and density and working formulæ are given for all the quantities entering into the design problems discussed. Numerical examples are worked out and the results shown in tables and graphically. The effects of small changes in the condition are considered in detail.

Approximate generalised curves of climb, speed and starting are obtained and characteristics of numerous typical aircraft show reasonable narrow scattering.

The articles are a useful practical course for designers.

Aeroplane Maximum Speed. (F. M. Thomas and H. W. Fairchild, S.A.E. Jrnl., Vol. 32, No. 3, March, 1933, pp. 78-86.) (7.15/26527 U.S.A.)

The assumption is made that engine b.h.p. is proportional to the reciprocal of absolute temperature, and this relation is combined with the usual aeroplane and airscrew formulæ to obtain the best combination for maximum speeds by means of charts and abacs (nomograms).

Notes on Long Range Aeroplanes. (M. Constantin, L'Aérophile, No. 1, Jan., 1933, pp. 16-17.) (7.15/26528 France.)

Aeroplanes are subject to additional drag from negative lift on the tail control surfaces. Shifting the centre of gravity farther back decreases the tail load and drag but affects the stability adversely. An automatic wind vane device maintains constant incidence and reduces the tail surface drag. An increased radius of action is claimed.

Devices for Increasing Lift. (Z.F.M., Vol. 24, No. 2, 28/1/33, p. 62.) (7.20/26529 Germany.)

The Fowler wing has an auxiliary wing of the same section placed at a greater angle of incidence behind the main wing, with an intervening slot space, which is closed by housing the auxiliary wing in the rear portion of the main wing. The lift is nearly trebled in the open slot position.

Comparative tests were made with the Lachmann slotted wing.

Engines—Thermodynamics

Changes of State of Ideal Gases with Finite Velocity. (L. Vahl, Forschung, Vol. 4, No. 1, Jan.-Feb., 1933, pp. 31-37.) (8.10/26530 Germany.)

The effect of piston speed on the compression of air and CO_2 and SO_2 is investigated. The absence of thermal equilibrium entails an increase in work spent on the piston which may reach 2 per cent. for moderate piston speeds of the order of 10 m. per sec. Piston speeds have a profound effect on Carnot cycle efficiencies. With SO_2 between 0 and 20°C., the maximum realisable efficiency is only 50 per cent. of the ideal, with infinitely slow piston travel.

Gaseous Combustion at High Pressure—Explosion of H_2/Air and Carbonic Oxide Air Mixtures. (W. A. Bone, D. M. Newitt and D. T. A. Townend, Proc. Roy. Soc., Vol. 139, No. A.837, 2/1/33, pp. 57-74.) (8.13/26531 Great Britain.)

Explosions of hydrogen-air and carbonic oxide-air mixtures were carried out at initial pressures up to 1,000 atmospheres. The activation of N_2 previously observed with carbonic oxide-air mixture was confirmed and found to reach a maximum at approximately 500 atmospheres initial pressure. The activation is apparently due to radiation emitted by the CO flame and absorbed by the N_2 molecules.

Gaseous Combustion at High Pressure—Formation of Nitric Oxide in Carbonic Oxide-Oxygen-Nitrogen Explosions. (D. T. A. Townend and L. E. Outridge, Proc. Roy. Soc., Vol. 139, No. A.837, 2/1/33, pp. 74-83.) (8.13/26532 Great Britain.)

Explosions of carbonic oxide mixtures showed traces of nitric oxide. Commercial applications to fixation of atmospheric nitrogen would require a minimum yield of 10 per cent. at an initial pressure of 75 atmospheres. The explosion chamber was separated from a large expansion chamber by a " notched " diaphragm designed to blow out at a predetermined pressure. The rapid cooling thus obtained gave a maximum yield of 5.4 per cent. nitric oxide.

Gaseous Combustion at High Pressure—Nitric Oxide Formation in Continuous High Pressure Flames of Carbonic Oxide in Oxygen Nitrogen Mixtures. (D. M. Newitt and F. G. Lamont, Proc. Roy. Soc., Vol. 139, No. A.837, 2/1/33, pp. 83-93.) (8.13/26533 Great Britain.)

Haber in 1909 has obtained yields of the order of 1 per cent. by burning CO in " Linde " air at 10 atmospheres. A pressure of 100 atmospheres doubled the yield in these new experiments. The conditions in a flame are less favourable to NO formation than on explosion in a bomb, and this is shown in the smaller yield.

The Combination of Hydrogen and Oxygen Photo-Sensitised by Nitrogen Peroxide. (R. G. W. Norrish and J. G. A. Griffiths, Proc. Roy. Soc., Vol. 139, No. A.837, 2/1/33, pp. 147-162.) (8.13/26534 Great Britain.)

Previous conclusions (of Haber, Hinshelwood and others) confirm that the reactions between hydrogen and oxygen are of the chain type and can be sensitised by the introduction of hydrogen atoms. The present paper extends the work of Hinshelwood and Thompson and shows that the chains can also be sensitised by the introduction of oxygen atoms found by the decomposition of the nitrogen peroxide. In terms of petrol pressure less than .25 mm. of nitrogen peroxide in a total of 150 mm. will produce rapid formation of water at 357°C.; without the nitrogen peroxide no measurable reaction is obtained below 500°C.

Determination of Flame Temperature. (B. Lewis, H. Seaman and G. W. Jones, J. of Frank. Inst., Vol. 215, No. 2, Feb., 1933, pp. 149-167.) (8.13/26535 U.S.A.)

In continuation of three previous papers on determination of flame temperature of various combustible mixtures, the same methods are used to determine flame temperatures of more complex mixtures such as hydrogen, methane and carbon monoxide with oxygen and air, with added nitrogen and carbon in various amounts.

Results are given in diagrams and numerical tables in comparison with calculated heats of combustion, with some worked out examples.

Six references.

Engines—Design and Performance

Comparison of Aero and Auto Engines, etc. (Dipl.-Ing. Kurz, Autom. Tech. Zeit., Vol. 35, Nos. 10-11 and 13-17, 1932.) (8.20/26536 Germany.)

Comprehensive groups of engines for different purposes are considered and two fundamental characteristics—r.p.m. and inertia forces—are plotted against cylinder volume. The points are widely scattered, but their general run is clearly observable.

The mechanical stressing of various types of car and aero engines is compared. Whilst the aero engine of large and medium power output is generally stressed higher than the racing car engine, the light aeroplane engine of the standard four-cylinder type is less heavily stressed than the engine on a sports car. This probably accounts for the great reliability of the light aeroplane engine.

The New Improved Hornet Engine, Type T.1C. (Autom. Tech. Zeit., Vol. 36, No. 2, 25/1/33, p. 39.) (8.20/26537 Germany.)

The complete engine weighs 395 kg., has an effective cylinder volume of 27.7 litres and develops 700 h.p. at 2,000 r.p.m., with a compression ratio 6/1. A centrifugal fan booster necessitates a fuel of high octane ratio—87. The fin area of the cylinder has been increased, an oil temperature regulator is installed, the exhaust valves are cooled and the crankshaft specially hardened. A Hamilton variable pitch airscrew is fitted.

New Model of Benz Injection Oil Engine. (Z.V.D.I., Vol. 77, No. 1, 7/1/33, p. 29.) (8.25/26538 Germany.)

Instead of the former central injection, the needle valve and chamber are placed at an angle and enter the cylinder near the wall, giving space for larger valves with increase of volumetric efficiency.

One reference.

New Ceramic Materials. (W. Steger, Z.V.D.I., Vol. 77, No. 4, 28/1/33, pp. 81-87.) (8.283/26538 Germany.)

Tables are given of mechanical strength, thermal expansion and heat conductivity of porcelain clays, rare earths, quartz, etc.

A new clay, with the trade name Sinterkorund, has good electrical insulation with a heat conductivity nearly ten times that of porcelain, a combination of qualities desirable in sparking plugs.

The Use of Water Injection in Internal Combustion Engines. (H. R. W. Schreiber, Autom. Tech. Zeit., Vol. 36, No. 2, 25/1/33, pp. 32-33.) (8.29/26540 Germany.)

In hot bulb engines of low efficiency water injection reduces the temperature and acts definitely as a catalyser with improved combustion of the fuel oil.

In high efficiency internal combustion engines corrosion and crankcase oil dilution outweigh possible advantages. Useful applications of water injection are restricted to steady full load conditions.

Jet Propulsion with Reference to Thrust Augmentors. (G. B. Schubauer, N.A.C.A. Tech. Note No. 442.) (8.297/26541 U.S.A.)

A summary is given of the principles and possibilities of jet propulsion. At ordinary aeroplane speeds the relative inefficiency of propulsion by jet in comparison with airscrew propulsion is decisive.

For flight in the stratosphere rocket propulsion efficiency is equal to that of the airscrew at about 800 m.p.h., but the difficulties of starting, landing and controlling the combustion render the whole scheme illusory in the present state of technical development. The problem of increasing the jet efficiency by multiple nozzles is discussed at length and experimental characteristics of a variety of types are given in tables graphically.

At ordinary flying speeds there is a slight improvement in efficiency which leaves the jet still far inferior to the airscrew.

Dimensioned sketches show the details of simple and multiple nozzles used in the investigation, and a photograph shows the experimental mounting.

Twenty-three references.

Engines—Accessories

Resonance Torsional Oscillation Damper with Solid Damping for Crankshafts of Diesel Engines. (W. Popoff, Z.V.D.I., Vol. 77, No. 1, 7/1/33, pp. 19-23.) (8.36/26542 Germany.)

The damper consists of a hollow cylinder of rubber, surrounding the shaft, with its ends clamped to discs rigidly attached to the shaft. The damper is tuned by slipping additional rubber rings over the cylinder, till resonance is obtained under working conditions.

Numerical results are given graphically and in tables, and show the beneficial effects of damping in several installations. Four oscillograms are reproduced.

Seven references.

Irregular Firing and Torsional Oscillation. (M. Scheuermeyer, Werft-Reederei-Hafen, No. 5, 1/3/33, pp. 59-61.) (8.36/26543 Germany.)

Fourier series are formed to express the periodic torques, vector diagrams are drawn and resulting torque variations are tabulated and shown graphically.

Whirling of a Journal in a Sleeve Bearing. (D. Robertson, Phil. Mag., Vol. 15, No. 96, Jan., 1933, pp. 113-130.) (8.37/26544 Great Britain.)

Osborne Reynolds' theory of lubrication applies to steady motion. Extensions to the case of whirling shafts require much more elaborate treatment on account of the periodic changes in depth and velocity of lubricant. Critical reference is made to subsequent work.

The author states the usual assumption, and forms the numerous expressions required in the subsequent analysis. The results are compared with experiments and agree in important respects. At still higher speeds discrepancies appear which may be due to whipping and to turbulence in the lubricant.

Eight references.

Improvements in Light Alloy Piston for Motor Car Engine. (Z.V.D.I., Vol. 77, No. 2, 14/1/33, p. 54.) (8.38/26545 Germany.)

The ring grooves of a Silumin piston are made of a special cast iron, cast into the piston head. The wear is considerably reduced and new rings can be fitted without remachining the grooves.

Engines—Cooling

The Principles of Air Cooling. (D. R. Pye, Airc. Eng., Vol. 5, No. 48, Feb., 1933, pp. 31-33; also March and April.) (8.40/26546 Great Britain.)

The flow of air in the so-called boundary layer is discussed with reference to modern experimental and mathematical work. Observed velocities are given graphically as functions of position, semi-empirical expressions in current use are quoted, and applications to heat transference are considered, all with reference to smooth surfaces of simple form.

Estimates of the rate of heat dissipation imposed on the cylinder cooling surface give a round figure of 50-60 per cent. of the b.h.p. The provision of fins exposed to the air increases the head resistance; the best compromise is discussed with numerical illustrations.

Reference is made to the analogy between transference of heat by conductivity and of momentum by viscosity, and of both by eddy connection in turbulent flow, and formulæ, at best of a semi-empirical nature, are given in a form suitable for numerical evaluation in c.g.s. units, as the inconsistent units of English engineering are confusing in problems of any physical complexity. The importance and difficulty of this part of the subject are indicated by the space given to it.

Even for simple mathematical forms the thermo-hydrodynamical problem is intractable, and the scheme given by the author for application to engine design is based on comprehensive technical experience.

Useful practical principles are given for the guidance of designers.

Heat Transmission and Cylinder Wall Temperature in High Temperature Liquid Cooling. (H. Oestrich, Z.F.M., Vol. 24, No. 4, 28/2/33, pp. 109-113. D.V.L. Report 312.) (8.44/26547 Germany.)

With high temperature liquid cooling the actual amount of heat to be dealt with by the radiator is appreciably less than with water cooling. The difference is entirely due to the higher temperature of the cylinder, the surface of which acts as a supplementary radiator.

Engines—Lubricants and Lubrication

Oil Testing Machines. (Autom. Tech. Zeit., Vol. 36, No. 1, 10/1/33, pp. 13-15.) (8.540/26548 Germany.)

The results obtained from oil testing machines can only be appreciated by trained experimenters.

In the machine developed for research purposes at the Technical High School, of Karlsruhe, bearing temperatures and loads are kept constant and the coefficient of friction is plotted over a wide speed range, including the regions of complete and partial fluid lubrication. This so-called " Stribeck " curve is applied to classify oils. For acceptance tests a modified Suthau machine is recommended, in which constant speed is maintained, a fixed quantity of oil is introduced and observation is made of the time required for a specified increase in resistance as indicated by the deflection of a pendulum.

Comparative figures obtained by the latter machine are for castor oil 5 hours, for mineral oil 1 hour, and for glycerine 20 minutes.

Oil Discoloration in Use. (Autom. Tech. Zeit., Vol. 36, No. 1, 10/1/33, pp. 19-20.) (8.540/26549 Germany.)

Discoloration of oil in an internal combustion engine depends on initial fluorescence and by itself is no indication of deterioration or loss of lubricating power.

The Present Position of Scientific Bearing Design. (O. Schweickhart, Autom. Tech. Zeit., Vol. 36, No. 1, 10/1/33, pp. 1-5.) (8.580/26550 Germany.)

Falz has introduced simplifications into the lubrication theory of Gumbel and Everling. Deformations of bearings or shaft are more important in determining the life of the bearing than the so-called *PV* factor. Misapplied hydrodynamic theory imposed relatively long bearings to reduce end leakage. It appears that much shorter bearings with relatively small deformation give better results.

Twenty references.

Engines—Fuels

Gas and Light Oil from Lignite Tar. (A. Sander, Z.V.D.I., Vol. 77, No. 4, 28/1/33, pp. 100-101.) (8.602/26551 Germany.)

Tar and water are sprayed through small orifices into a reaction chamber maintained at a temperature between 800° and 1,000°C. under atmospheric pressure. After leaving the chamber the gases are rapidly cooled, by water injection, to 300°C., with consequent deposition of pitch and asphalt.

Subsequent cooling is carried out by stages in air condensers. Temperature control in the reaction chamber determines a predominantly gaseous or liquid yield; 1 kg. of tar will yield up to 2 cubic m. of gas and 200 grs. of liquid fuel.

Two references.

New Process for Alcohol Production. (K. W. Geisler, Z.V.D.I., Vol. 77, No. 5, 4/2/33, pp. 126-128.) (8.606/26552 Germany.)

Apart from methods of fermentation ethyl alcohol is produced commercially from wood or ethylene, and from acetylene by addition of free hydrogen. The last method is being investigated in France. Ammonium sulphate is produced as a by-product by treating ethyl sulphuric acid with ammonia. The latter is obtained from the H_2 contained in coke oven gas.

Anti-Knock Research. (C. B. Veal and others, S.A.E. Jrnl., Vol. 32, No. 3, March, 1933, pp. 105-119.) (8.045/26553 U.S.A.)

The policy of the Co-operative Fuel Research Committee is stated. The laboratory equipment and test methods are described in relation to comparative road tests.

Sectional sketches are given of the front and side elevations of the test engine and of experimental gear for fuel intake control. Graphical records are shown of results in road tests and in the laboratory. Some rather unsystematic conclusions are drawn, and further test direction is indicated.

Eighteen references.

Engines—Injection Systems

Bosch Carburettors. (Autom. Tech. Zeit., Vol. 36, No. 1, 10/1/33, pp. 12-13.) (8.701/26554 Germany.)

The carburettors are fitted with a cold starting device controlled by a second float, which prevents flooding of the engine. In a modified form, a sealed flat chamber is used and the autovac dispensed with, the carburettor performing its own lifting of the fuel.

The article is illustrated by a photograph and three sectional diagrams with names of parts.

Process of Guttulation (Atomisation) of Jet in Diesel Engines without Compressor. (O. Klusener, Z.V.D.I., Vol. 77, No. 7, 18/2/33, pp. 171-172.) (8.705/22.2/26555 Germany.)

Each drop of fluid is exposed to the pressure of the relative wind, which tends to deform it against the surface tension which tends to maintain the spherical form. The known distribution of pressure on a sphere is plotted and the subsequent deformation of the drop is considered. Probable diameters and speeds of drops are correlated with temperature and pressure in graphical charts.

Experimental points given by Fr. Sass are marked on the chart and confirm at least the order of magnitude of the predicted values.

Guttulation (Atomisation) of Liquid Jets. (H. H. Holroyd, J. Frank. Inst., Vol. 215, No. 1, Jan., 1933, pp. 93-97.) (22.2/26556 U.S.A.)

The volume of the drop is expressed as the ratio [(surface tension × square of jet dia.) ÷ (density of fluid × square of jet velocity)] multiplied by an undetermined function of the Reynolds number.

Experimental tables show that with this parameter the function of Reynolds number changes slowly increasing jet pressures. (The effect of air forces does not receive consideration so that the author's physical reasoning may require some modification.)

Engines—Exhaust Systems

Silencers for Motor Car Engines. (E. Lehr, Z.V.D.I., Vol. 77, No. 1, 7/1/33, pp. 26-27.) (8.721/26557 Germany.)

Apparatus is described for analysing the frequency of the sound emitted by the exhaust of an engine run under various conditions. Measurements of noise intensity and pressure amplitude were made with various types of silencers. The best results were obtained by combining two types of silencers, one in which the gas passes through a series of expansion chambers, the expansion from one chamber to the next being sudden. This is effective in destroying notes of low frequency. The second type of silencer is of the so-called absorption type, *i.e.*, a tube of constant cross-section is lined with a porous material which silences the high frequency note.

Two references.

Flow in Cross-Section of Inlet Valve of High Speed Internal Combustion Engines. (K. Schlaefke, Autom. Tech. Zeit., Vol. 36, No. 2, 25/1/33, pp. 28-31.) (8.725/26558 Germany.)

Simplifying assumptions are made and the air velocity through the valve throat is computed for every 2° of crank angle.

The maximum velocity and the corresponding crank angle depend on the compression ratio. With increasing compression ratios increasing maximum values are reached at decreasing crank angles.

Engines—Transmission

Clutch Design. (E. E. Wemp, S.A.E. Jrnl., Vol. 32, No. 3, March, 1933, pp. 92-103.) (8.765/26559 U.S.A.)

The problems of design include spring pressure and cover plate, disc facing and distortion, manual operation, automatic centrifugal action, free wheeling and fluid couplings. Vacuum control is discussed. Drawings are reproduced of thirteen types of clutch.

Armament

Ballistics of Rifles. (H. Gerlich, Army Ordnance, Vol. 13, No. 76, Jan.-Feb., 1933, pp. 215-219.) (9.16/26560 U.S.A.)

The author makes remarkable claims in respect of bullet speeds. A previous claim to maximum muzzle velocity of 5,710ft. per sec. has been criticised by a German authority as impossible, but the author now produces test figures showing a muzzle velocity of 4,445ft. per sec. and states that similar results were obtained officially (in U.S.A.).

Photographs of penetration of armour plate by the author's rifle bullets are reproduced.

The Combustion Problem of Internal Ballistics. (A. D. Crow and W. E. Grimshaw, Phil. Mag., Vol. 15, No. 99, March, 1933, pp. 529-553, and No. 100, April, 1933, pp. 729-752.) (9.16/26561 Great Britain.)

The whole problem of internal ballistics is reconsidered in the light of developments to date. Expressions are formed for the pressure density relation, the rate of burning, the transformation of energy into kinetic energy of travel or spin, friction loss and heating.

The solution of the system of differential equations in non-dimensional form forms a lengthy contribution to methods of numerical solution which is unsuitable for abstraction.

Night Bombing—Past, Present and Future. (Lieut.-Col. Hébrard, Rev. F. Aér., No. 42, Jan., 1933, pp. 5-60; No. 43, pp. 123-150; No. 44, pp. 245-275.) (9.3/26562 France.)

Night bombers may operate on the battlefield against railheads and dumps immediately supplying the fighting troops, or finally against the enemy civilian population, particularly where engaged in war production.

The desired characteristics of bombing aircraft vary with the different objectives. Special equipment is required for recognition of the objective by searchlight or flash bomb. Developments in photography will extend the scope of night work, especially in detecting the movements of large masses of troops by night.

For a defensive measure first place is given to the fast fighters. Reference is made to development of listening posts by Great Britain, suggesting that searchlights will not be used, but that bombers will be located acoustically and fighting squadrons directed accordingly.

Gunnery and Bombing (Naval)—Ballistics. (L. Thompson, J. Frank. Inst., Vol. 215, No. 2, Feb., 1933, pp. 119-132.) (9.33/26563 U.S.A.)

General principles are considered in relation to attacks by bombers from a carrier ship against effective defence by fighters and anti-aircraft guns.

An attempt is made to assess the weighting of different factors and to establish probability of loss and of hit. Formulæ are developed, but stress is laid on the uncertainty of the relative weights of the numerous factors.

A comparison is made with long range fire by heavy naval battery.

Armour v. Bullets. (G. P. Wilhelm, Army Ord., Vol. 13, No. 76, Jan.-Feb., 1933, pp. 207-210 and 242.) (9.57/26564 U.S.A.)

A number of technical data are given in respect of high resistance steels and high penetration bullets.

The effects on concrete shelters, steel helmets and tank armour are discussed.

Alkan Cinematic Target. (Rev. F. Aer., No. 43, Feb., 1933, pp. 219-227.) (9.62/26565 France.)

A description is given of equipment for training in navigation and bombing by sighting on a moving projection of a landscape, illustrated by six diagrammatic sketches with 78 numbered details.

The O.P.L. Camera Gun (Rev. F. Aer., No. 42, Jan., 1933, pp. 107-111.) (9.63/26566 France.)

The camera gun resembles in appearance the Hotchkiss machine gun. It is intended for anti-aircraft practice and takes account of the motion of the target aircraft, the time of flight of the bullet and the curvature of the trajectory.

Fennel Range-Finder. (R. Werkmeister, Z. Instrum., Vol. 53, No. 2, February, 1933, pp. 82-84.) (9.64/26567 Germany.)

The instrument is intended for accurate survey work. Distance ranging from 50-100 m. can be measured to an accuracy of ± 2.5 cm. with a single observation.

Materials—Characteristics

Manufacture and Use of Light Alloys. (W. C. Devereux, J.R. Aer. Soc., Vol. 37, No. 266, Feb., 1933, pp. 145-167.) (10.231/26568 Great Britain.)

The tensile strength and Brinell hardness of four alloys are shown as a function of temperature up to 350°C. Friction tests on cast piston alloys show relative friction as a function of temperature up to 220°.

Fatigue tests up to 40 million reversals show the high fatigue strength of " Y " alloy and " Hiduminium " in comparison with 2.L.8. Data from impact tests and heat treatment are tabulated.

Special Light Alloys for Aircraft. (W. C. Devereux, Airc. Eng., Vol. 5, No. 47, Jan., 1933, pp. 6-12.) (10.231/26569 Great Britain.)

Extensive information is given from the practical experience of the author with Y-metal, hiduminium and other known trade alloys.

Photographs are reproduced illustrating casting and stamping problems.

Three machines for friction fatigue and repeated impact tests are shown. Metallurgical peculiarities of specimens under varied heat and mechanical treatment are exhibited by metallographical photographs and by graphical charts of tensile strength, Brinell hardness, elongation, as functions of temperature and number of stress reversals, etc.

Copper-Beryllium Alloy. (Sci. Am., Vol. 148, No. 3, March, 1933, p. 170.) (10.234/26570 U.S.A.)

The American Brass Co., Bridgeport, Connecticut, has exhibited a new alloy copper + 1 to 2¾ per cent. beryllium with elastic limit 170,000lb. per sq. in. (75 tons), susceptible of heat treatment with high electrical conductivity and resistant to corrosion.

Instrument for Measuring Flexural Characteristics of Textiles. (H. F. Schiefer, Bur. Stan. J. Res., Vol. 10, No. 5, May, 1933, pp. 647-657.) (10.402/26571 U.S.A.)

A strip of fabric is mounted so that it can be bent by couples at each end of the free length into a circular arc, the minimum angle subtended at the centre of the arc being kept proportional to the thickness of the material, so that the strains in the extreme inner and outer surfaces are equal. The torque work required to produce the strain is plotted against the angle for bending in the planes of the warp and the filling. There is marked hysteresis on relaxing the bending strain.

An interpretation of the results in terms of trade qualities of " feel " and " handling " is suggested.

Seven references.

Materials—Defects and Treatment

Fatigue Strength of Nitrided Test Pieces. (R. Mailander, Z.V.D.I., Vol. 77, No. 10, 11/3/33, pp. 271-274.) (10.120/26572 Germany.)

The advantages of nitriding apply not only to ordinary metal forms, but to regressive edges with small radii such as are produced by grooves, notches and screw threads.

A number of test results are reproduced in illustrations. The relative merits of cadmium and zinc protection are discussed.

Twelve references.

New Process of Welding by Gas or Electric Arc. (E. Kalisch, Z.V.D.I., Vol. 77, No. 13, 1/4/33, pp. 355-356.) (10.140/26573 Germany.)

The absorption of carbon during welding may harden the material locally and reduce the extension under tensile test. A process of annealing is applied which redistributes the excess carbon more uniformly. Four photographs show the metallurgical processes. (German Patent D.R.P.a.K.120073.)

The Effect of Alcoholic Fuels on Aluminium and its Alloys. (O. Bauer and G. Schikorr, Z. Metallk., Vol. 25, No. 2, Feb., 1933, p. 44.) (10.262/26574 Germany.)

Corrosion effects are entirely due to the presence of water in alcohol fuels or mixtures. They become active when the water content exceeds one per cent. The corrosion was uniformly distributed over the alloy and was practically the same for pure aluminium as for the alloy tested.

Cohesive Strength. (W. Kuntze, Z.V.D.I., Vol. 77, No. 2, 14/1/33, pp. 49-50.) (10.660/26575 Germany.)

In the standardised tests for cohesives, too little attention is given to the shape of the test pieces, the results for which may have little direct application under complex stresses in practical applications.

Four references.

Nail Tests. (H. J. Ströer, Z.V.D.I., Vol. 77, No. 1, 7/1/33, pp. 13-18.) (10.90/26576 Germany.)

Nails are retained in position by tangential friction produced by the normal pressure of material. In wood, the pressure due to displacement of longitudinal fibre is more effective than that due to transverse fibres.

It is advisable that the nail be well pointed, roughened, and driven in at an angle, especially if the wood is moist. Experimental values are given in tables and graphically, and bring out the importance of nail section and point.

Photographs of nine sectioned specimens show the greater or less disruption of the wood fibres by the different sections.

Eight references.

Testing Apparatus, etc.—Altitude Chambers

Effect of Altitude on Gas Appliances. (J. H. Eiseman, F. A. Smith and C. J. Merritt, Bur. Stan. J. Res., Vol. 10, No. 5, May, 1933, pp. 619-637.) (11.60/26577 U.S.A.)

The investigation is directed to the behaviour of gas jets in various domestic appliances to ensure safety in installations at great heights above sea level. A reduction of 3 to 4 per cent. in gas rate for each 1,000 feet above sea level is prescribed.

The low-pressure test chamber and the analysis of the gases are cognate to aeronautical problems.

Five references.

Airships

Motion of an Airship under Certain Conditions. (D. H. Williams and A. R. Collar, J.R. Aer. Soc., Vol. 37, No. 265, Jan., 1933, pp. 35-75.) (12.10/26578 Great Britain.)

Consideration is restricted to the motion of the R.101 in a vertical plane under disturbing forces imposed by control surfaces, change of airscrew thrust, internal changes of trim and buoyancy and external air forces due to gusts.

The mathematical equations of longitudinal stability are intractable save for small disturbances, and graphical and numerical methods are required for large disturbances. Six characteristic derivatives are required in the equations of motion, and are given graphically.

The trajectories are worked out from point to point for a variety of conditions and show the path subsequent to the disturbance.

Some of the effects are quite unexpected in relation to their causes, and show that apparently obvious correcting manœuvres may well accentuate the departure from steady flight and precipitate a disaster.

The authors conclude that problems of airship stability should be worked out in advance, for comparison with test observations.

Seven references.

Airship Development Abroad. (S.-Ldr. R. S. Booth, J.R. Aer. Soc., Vol. 37, No. 268, April, 1933, pp. 366-380.) (12.10/26579 Great Britain.)

The main constructional features of the American and German airships are reviewed. Of special interest is the statement that the short life of the gas bags on the British ships R.100 and R.101 was due to the outer covering being faulty and thus providing insufficient protection. If properly installed, a gas bag has a useful life of several years.

Airship Problems. (K. Arnstein, Z.F.M., Vol. 24, No. 1, 14/1/33, pp. 1-13.) (12.10/26580 Germany.)

A note is given on the historical development of rigid airships.

A detailed descriptive technical account is given of the numerous aerodynamical, aerostatical, structural and propulsive problems involved. A general arrangement sketch and twenty photographs show numerous details.

Two references.

Technical Notes on the "Graf Zeppelin." (C. Dollfus, L'Aéron., No. 164, Jan., 1933, pp. 15-20, and No. 165, Feb., 1933, pp. 39-42.) (12.30/26581 France.)

The author was a passenger from Friedrichshafen to Pernambuco and back and comments favourably on the technical equipment and handling of the ship. Fourteen photographs are reproduced.

The airship steers better without the rear airscrew, the wake of which affects the controls, and for this reason the rear engine is generally kept in reserve. The engine builders were given a free hand as to engine weights with high reliability and low consumption as the chief consideration.

The weight is 4lb./h.p. at 450 h.p. and 1,450 r.p.m. at which the engine will operate continuously for 2,000 to 3,000 hours without overhaul. The gas used is H_2 and Blaugas, stored at refuelling stations in short fat cylinders.

The electrical installation consists of two 30 h.p. petrol engines driving two 25 k.w. generators, all housed in a separate gastight gondola, insulated from the rest of the airship. The loss of lifting gas through the ballonets is less than 50 m.^{3} per day (total capacity of ship 70,000 m.^{3}).

The author urges co-operation with the Zeppelin Co. by the erection of landing masts and airports in France. In this way American passengers are saved a possibly unnecessary journey to Friedrichshafen.

Wireless

High Power Broadcasting Equipment in Germany. (A. Semm, Z.V.D.I., Vol. 77, No. 10, 11/3/33, pp. 257-264.) (13.0/26582 Germany.)

A descriptive technical account is given of installations at Muhlacker (Stuttgart), Breslau, Berlin and Hamburg.

Thirteen photographs show the external appearance of parts of the equipment.

Eight references.

Audio Transformer. (M. Pawley, J. Frank. Inst., Vol. 215, No. 2, Feb., 1933, pp. 133-147.) (13.2/26583 U.S.A.)

A selective amplifier circuit is shown in diagram containing an audio transformer with variable resistance in the primary and a variable capacitance in the secondary.

Elementary expressions give the relations between resistance, capacitance, voltage, amplification and frequency. Characteristic curves are shown graphically.

Numerical examples are worked out and oscillogram records are reproduced to illustrate the selectivity of the circuit.

Elimination of Background "Noise" in Sensitive Pulse Amplifiers. (L. F. Curtiss, Bur. Stan. J. Res., Vol. 10, No. 2, Feb., 1933, pp. 151-154.) (13.2/26584 U.S.A.)

From author's abstract:—Even after due care has been taken to reduce disturbances in the first two stages, a great improvement can be effected by suitable modification of the final or output stage. This consists in using several output tubes, preferably pentodes, in parallel, and selecting an operating point on the characteristic curve such that small fluctuations in the voltage applied to the

control grids produce practically no change in the plate current and yet all pulses which exceed these fluctuations in the desired direction are reproduced in the plate current. Although this arrangement involves some distortion of very small pulses, the gain in the legibility of the oscillograph record is sufficient to compensate for this slight disadvantage. The results obtainable under various conditions are illustrated by reproductions of oscillograph records.

Equipment for Audio-Frequency Amplifiers. (H. Sohon, Proc. Inst. Rad. Eng., Vol. 21, No. 2, Feb., 1933, pp. 228-237.) (13.2/26585 U.S.A.)

From author's abstract:—A new type peak voltmeter is described that makes continuous measurements of the highest peak values attained by the signal.

An automatic control circuit is described which reduces the amplification of a special amplifier when the output voltage reaches a certain amount, thereby keeping the subsequent equipment from being overloaded.

Analysis of Parallel Resonance. (R. Lee, Proc. Inst. Rad. Eng., Vol. 21, No. 2, Feb., 1933, pp. 271-281.) (13.2/26586 U.S.A.)

From author's abstract:—Vector diagrams are developed for various conditions of tuning parallel circuits, and from the geometry of the diagrams mathematical relations are derived. These relations are then plotted for use in tuning operations. Two examples are given of the practical application of the analysis.

North Atlantic Ship-Shore Radiotelephone Transmission 1930-31. (C. N. Anderson, Proc. Inst. Rad. Eng., Vol. 21, No. 1, Jan., 1933, pp. 81-101.) (13.31/26587 U.S.A.)

From author's abstract:—Contour diagrams are given which show the variation of signal fields with distance and time of day for the various seasons on approximate frequencies of 4, 9, 13 and 18 megacycles. Curves are also shown which enable the data to be applied more generally for other conditions of noise and radiated power.

Cause and Elimination of Night Effect in Radio Range-Beacon Reception. (H. Diamond, Bur. Stan. J. Res., Vol. 10, No. 1, Jan., 1933, pp. 7-34.) (13.4/26588 U.S.A.)

An approximate analysis is given of the effects produced at night on waves propagated by loop antenna rotation of the plane of polarisation of horizontal components of the electrical wave, which produces an effective rotation of the beacon pattern in space.

Continuous reception records show variations in apparent direction exceeding $\pm 30^\circ$ within a few minutes and reaching $\pm 45^\circ$.

The application of vertical antennæ reduced these variations to the order of $\pm 3^\circ$.

Reference is made to earlier British developments on similar lines.

Eight references.

The Cathode Ray Oscillograph. (R. A. Watson Watt, J. Sci. Inst., Vol. 10, No. 2, Feb., 1933, pp. 37-43.) (13.5/26589 Great Britain.)

The fundamental merit of the cathode ray oscillograph lies in the elimination of inertia and corresponding time lag for recording speeds up to half that of light.

Important applications are described and four oscillograms are reproduced.

Grid Controlled Mercury Vapour Tube. (A. C. Seletzky and S. T. Shevki, J. Frank. Inst., Vol. 215, No. 3, March, 1933, pp. 299-326.) (13.5/26590 U.S.A.)

The tube is essentially a triode operating in an atmosphere of mercury vapour. A diagram of connections is shown and the elementary physical relations are fully

stated. The characteristics are illustrated by 10 oscillograms and the reduced values are given in graphical charts.

Ellipse Diagram of a Lecher Wire System. (A. Hikosaburo, Proc. Inst. Rad. Eng., Vol. 21, No. 2, Feb., 1933, pp. 303-311.) (13.6/26591 U.S.A.)

The circuit for Lecher wire systems is shown diagrammatically and the vector equations are formed and discussed.

In graphical representation the current through the end of the system is the inverse of a radius vector drawn from a determinate origin to the periphery of an ellipse. An analogy with the circle diagram of an induction motor is pointed out.

Ultra-Short Wave Propagation. (J. C. Schelleng, C. R. Burrows and E. B. Ferrell, Proc. Inst. Rad. Eng., Vol. 21, No. 3, March, 1933, pp. 427-463.) (13.6/26592 U.S.A.)

From authors' abstract:—Part I of this paper describes a method of measuring attenuation and field strength in the ultra-short wave range. A résumé of some of the quantitative experiments carried out in the range between 17 megacycles (17 metres) and 80 megacycles (3.75 metres) and with distances up to 100 kilometres is given for (1) " Optical " paths over sea water and (2) " Non-optical " paths over level and hilly country. The absolute values of the fields measured were always less than the inverse distance value. Over sea water the fields decreased as the frequency increased from 34 megacycles (8.7 metres) to 80 megacycles (3.75 metres), while the opposite trend was found over land.

Part II gives a discussion of reflection, diffraction, and refraction as applied to ultra-short wave transmission. It is shown (1) that regular reflection is of importance even in the case of fairly rough terrain, (2) that diffraction considerations are of prime importance in the case of non-optical paths, and (3) that refraction by the lower atmosphere can be taken into account.

The existence of optimum frequencies is pointed out and it is emphasised that they depend on the topography of the particular paths, and that different paths may therefore have widely different optimum frequencies.

Twenty-one references.

Ultra-Short Wave Transmission Phenomena. (C. R. Englund, A. B. Crawford and W. M. Mumford, Proc. Inst. Rad. Eng., Vol. 21, No. 3, March, 1933, pp. 464-492.) (13.6/26593 U.S.A.)

From authors' abstract:—The results of a series of transmission experiments made in the range 3.7 to 4.7 metres and over distances up to 125 miles are reported. These observations were chiefly confined to the region reached by the directly transmitted radiation and are found in good agreement with the assumption that such transmission consists mainly of a directly transmitted radiation plus the reflection components which would be expected from the earth's contour.

The almost universal standing wave diffraction patterns have been studied and sample records are given. The methods of measuring field intensity are described in an appendix. No long-range transmissions, such as harmonics of distant (greater than 500 miles) short-wave stations would yield, have been observed.

Seven references.

Measurement of Frequency of Short Waves. (B. Hoag, Proc. Inst. Rad. Eng., Vol. 21, No. 1, Jan., 1933, pp. 29-36.) (13.6/26594 U.S.A.)

A Lecher wire system, short circuited by a Tonks bridge, with impedance approximately equal to that of the input oscillator, develops an e.m.f. which is periodic in the difference between the wave length and the length of the shorted wires.

The galvanometer deflection produced by a rectified current exhibits this periodicity and enables a number of wave length determinations to be made. The mean values for wave lengths from 20 to 60 cm. are given to three significant figures.

Propagation of Wave Lengths between Three and Eight Metres. (L. F. Jones, Proc. Inst. Rad. Eng., Vol. 21, No. 3, March, 1933, pp. 349-386.) (13.6/26595 U.S.A.)

From author's abstract:—A description is given of the equipments used in an airplane, dirigible, automobile, and indoors to measure the propagation characteristics of wave lengths between about three and eight metres. The majority of observations were of television transmissions from the Empire State Building.

It is shown that any modulation frequency is partly or completely suppressed if propagation to the receiver takes place over two paths differing in length by half of the hypothetical radio wave length of modulation frequency.

Four references.

Propagation of Waves Below Ten Metres in Length. (B. Trevor and P. S. Carter, Proc. Inst. Rad. Eng., Vol. 21, No. 3, March, 1933, pp. 387-426.) (13.6/26596 U.S.A.)

From authors' abstract:—Observations of the two transmitters on the Empire State Building in New York City, on 44 and 61 megacycles, were made in an airplane over Long Island. These tests show the nature of the interference patterns set up by the combination of the direct and reflected rays. With low transmitting and receiving antennæ, field strength measurements with distance were taken for both horizontal and vertical polarisations over Long Island sand on 41.4 and 61 megacycles. Similar tests were made over salt water with low antennæ on 34.8 and 59.7 megacycles.

Another airplane test was made on 34 megacycles with a higher transmitting antenna and increased power up to a distance of 200 kilometres. The intervening territory in this run was partly land and partly salt water.

The experimental data are discussed in comparison with the theoretical curves determined from optical principles. The experimental results are shown to conform in general with the predictions from theoretical considerations.

Photo-Electric Emission in a Magnetic Field. (R. Schmid, Ann. d. Phys., Vol. 16, No. 6, March, 1933, pp. 647-656.) (13.7/26597 Germany.)

A magnetic field, parallel to the electric field of an open photo-electric cell, was found to increase the photo-electric emission.

A full technical description is given of the relatively simple apparatus, and some physical effects are discussed.

Electro-Physics. (N. R. Campbell, J. Inst. Elect. Engrs., Vol. 72, No. 434, Feb., 1933, pp. 153-159.) (13.7/26598 Great Britain.)

A concise review is given of progress in atomic physics. Applications to thermionic amplifiers, photo-electric cells, the electron microscope, piezo-electric clock control, and electric conduction are of general interest.

Electro-Motive Force of Copper Oxide Photo Cells as a Function of Light Intensity and Wave Length. (A. Goldmann and M. Lukasiewitsch, Phys. Zeit., Vol. 34, No. 2, 15/1/33, pp. 66-73.) (13.7/26599 Germany.)

The experimental method and installation are described in detail.

Various forms of the empirical equations are discussed, and close fits are obtained for observed values with red, green, and blue light. The e.m.f. is remarkably little affected by the wave length within the visible spectron.

Ten references.

Shielding at Radio Frequencies. (L. V. King, Phil. Mag., Vol. 15, No. 97, Feb., 1933, pp. 201-223.) (13.9/26600 Great Britain.)

Formal solutions are obtained in Legendre and Bessel functions for spherical and circular cylindrical shields, and simplified for various conditions.

At radio frequencies a simple exponential function with a shape factor is obtained.

The shape factor varies from 4 with a cylindrical shield to 6 for a spherical shield, and for any reasonable shape a mean diameter may be assumed with a shape factor between 4 and 6.

Electro-Magnetic Shielding. (W. Lyons, Proc. Inst. Rad. Eng., Vol. 21, No. 4, April, 1933, pp. 574-590.) (13.9/26601 U.S.A.)

Author's abstract:—The paper describes a method used in measuring the ratio of magnetic field intensities within conducting cylindrical and spherical shells to that outside, values being given for various frequencies between 1,000 and 30,000 cycles per second of the exciting field and various lengths and radii. A theoretical derivation of a shielding formula is given for a thin spherical shell and a cylindrical one of infinite length. Satisfactory agreement between theory and observation is found in the case of the sphere and in cylinders of lengths greater than their diameters.

Photography

Aerial Survey in Relation to Economic Geology. (D. Gill, J. Roy. Aer. Soc., Vol. 37, No. 267, March, 1933, pp. 227-287.) (14.14/26602 Great Britain.)

Cost and organisation are discussed briefly.

Applications for geological survey involve a number of special points and are still unsystematic. A reasoned scheme is suggested and covers equipment, choice of seasons and time of day, selection of scale, formation of mosaics and interpretation of geological features, all in relation to the dominating question of cost.

Thirty references.

Air Survey. (Lieut. J. S. A. Salt, J. Roy. Aer. Soc., Vol. 37, No. 267, March, 1933, pp. 209-226.) (14.14/26603 Great Britain.)

The geometry, technique and equipment required for air survey are dealt with concisely. Photographs show an R.A.F. automatic magazine camera installation and a Barr and Stroud stereoscopic comparator. Questions of organisation, policy and finance were raised in the subsequent discussion.

The Galliss-Ferber System of Rectification of Air Photographs. (E. Robin, Rev. F. Aer., No. 44, March, 1933, pp. 281-298.) (14.40/26604 France.)

The Galliss-Ferber machine for rectifying air photographs is described. No use is made of stereoscopy, but a method of stereoscopic illumination is employed. About 30 square kilometres of country can be covered by a pair of photographs 18 × 18 cm. from an altitude of 20,000 feet. Three pairs can be rectified in the apparatus per day. To cover a stretch of 100,000 square kilometres (1/5 the area of France) requires 6,700 couples taken in 84 flights of 4 hours each. The rectification would occupy about one year if six sets of apparatus are employed.

Sound, Noise Reduction, etc.

Acoustic Measuring Instruments for Practical Use. (W. Jackel, Z.V.D.I., Vol. 77, No. 4, 28/1/33, pp. 98-99.) (15.20/26605 Germany.)

A technical description is illustrated by three photographs and a diagram of connections. The pressure exerted by the sound wave is measured directly in

dynes/cm.^{2}, through a ribbon microphone with suitable rectification and amplification.

Another instrument dealing with the measurement of reverberation times, stores the energy electrically in a thermo element and measures it ballistically.

Seven references.

Gear Wheels as Sources of Sound. (A. Soden, Z.V.D.I., Vol. 77, No. 9, 4/3/33, pp. 231-238.) (15.3/26606 Germany.)

The kinematical conditions of contact are analysed in respect of tooth form and material. Diagrams show the profile of eight types of tooth profile with the rates of rolling and gliding of the point of contact, and the mechanical force applied. Methods of inspection are discussed and illustrated.

Oblique teeth are considered as an effective basis of reducing impact and noise. The dynamical measurement of sound intensity, as compared with subjective estimation, is illustrated by the reproduction of 15 oscillograph records. Numerous points remain obscure.

Twelve references.

Fundamental Investigation on Sound Absorption. (E. Wintergast and H. Klupp, Z.V.D.I., Vol. 77, No. 4, 28/1/33, pp. 91-95.) (15.3/26607 Germany.)

Fabrics stretched in one or two layers and fibre plates were placed at one end of a tube and a source of sound was operated at the other end of the tube. The maximum and minimum amplitude due to interference between incoming and reflected sound waves was measured by a travelling microphone, and the coefficient of absorption was determined therefrom.

The absorption of simple materials is dependent on sound frequency. Any attempt to widen the field of response reduced the absorption maximum. Best results over wide ranges were obtained by drilling a fibre plate with a large number of 5 mm. holes spaced 25 mm. apart. The plate itself is 18 mm. thick and placed 35 mm. from a solid wall; the intervening space was filled with slag wool.

The use of two layers of stretched fabrics placed close to the wall gives a higher degree of absorption, but is less effective at low frequencies.

Numerical results are given graphically in 12 diagrams and a table.

Three references.

The Problem of Noise from the Standpoint of the Engineer. (K. W. Wagner, Z.V.D.I., Vol. 77, No. 1, 7/1/33, pp. 1-9.) (15.3/26608 Germany.)

Recent developments in electro acoustics render possible accurate measurement of sound and noise intensity. The sound intensity in terms of air pressure may vary between 10^{-4} and 10^3 dyn./cm.^{2}. The noise intensity depends on the physiological characteristics of the human ear and is expressed on a logarithmic scale of decibels, the connection between air pressure and ear response being of the form

$$\text{Noise intensity in decibels} = cx \text{ by } 10\ p/ps.$$

p = air pressure of standard note producing equal ear response.

ps = air pressure of standard note at threshold of response.

Expressed on this scale, the ear response varies between 0 (threshold) and 150 phons or decibels, according to the frequency and the pressure of the sound waves. This scale is definite so long as the sounds are free from overtones, but difficulties arise when instruments are required to deal with complex sounds in the same way as the ear.

It is then necessary that the recording instrument in addition to measuring air pressure should also analyse the sound and add effects of the components in the same way as the ear. An instrument is described which does this fairly

satisfactorily for most sounds occurring in practice. In the case of explosive sounds, however, such as engine exhaust noises, a different procedure is adopted in which an impulse meter integrates the effect of short sound impacts. Examples are given in the use of such instruments for measuring engine noises, including those produced by gears.

Numerical results are given graphically and in tables. Numerous applications of sound damping in technical problems are illustrated by diagrammatic perspective drawings.

Eleven references.

Transmission of Sound through Partitions. (A. H. Davis, Phil. Mag., Vol. 15, No. 97, Feb., 1933, pp. 309-316.) (15.38/26609 Great Britain.)

For materials with poor elastic qualities such as paper, sail cloth, fibre board, the controlling parameter is the mass per unit area, but with very light partitions, such as thin paper, the damping effect becomes sensible. For mahogany panels and brick wall, resonance effects become important.

Comparison of experimental results with a formula given by Rayleigh brings out discrepancies which may be reduced by taking into account the more important modes of resonance of the partition regarded as an elastic plate.

Application of the Thermophone to Measurements of Threshold Sound Intensity. (W. Geffcken and L. Keibs, Ann. d. Phys., Vol. 16, No. 4, Feb., 1933, pp. 404-430.) (15.38/26610 Germany.)

The intensity of the sound wave produced in a closed space by a wire, of low heat capacity, traversed by an alternating current, can be calculated exactly from a formula given by mathematical physical theory, with one empirical coefficient.

The mathematical physical theory is worked out in detail and the conclusion is reached that it is the best method for exact determination of small sound intensities.

Aircraft—Unorthodox

Future Problems of Sailing Flight. (W. Georgii, Z.F.M., Vol. 24, No. 5, 14/3/33, pp. 125-136.) (17.40/26611 Germany.)

The performances of glider pilots have approached the limits imposed by the meteorological conditions in Germany. More extensive performances should be possible in the tropics. In the last competition at the Rhon previous direction and distance records were not broken, but better tuition has greatly improved the performance of the average pilot under normal weather conditions.

Wing Beats. (J. D. Batten, J.R. Aer. Soc., Vol. 37, No. 266, Feb., 1933, pp. 168-176.) (17.50/26612 Great Britain.)

A description is given of a mounting for wing spars permitting the beating of the wings with recuperation of the kinetic energy by a torsional spring.

The details are illustrated by sketches and photographs of model.

Meteorology and Physiology

Weather by Teletype. (Sci. Am., Vol. 148, No. 3, March, 1933, p. 169.) (19.0/26613 U.S.A.)

Teletype instruments are distributed at weather reporting stations along 13,000 miles of airway. Each station reports in rapid sequence and the messages are received on the tape by all other stations in the telephone cable circuit. Equipment for automatic re-transmission is provided at important airports.

A high standard of accuracy in short range forecasting is maintained.

Wind Pressure on Model of Empire State Building. (H. L. Dryden and G. C. Hill, Bur. Stan. J. Res., Vol. 10, No. 4, April, 1933, pp. 493-523.) (19.15/26614 U.S.A.)

The model is 5ft. high on scale 1/250.

A manometer was connected to orifices distributed over the model and gave pressure distribution, from which forces and moments over any section of the building could be calculated, at every ten degrees of orientation about a vertical axis. The results are given in tables and graphically.

Seventeen references.

Proposed Physiological Standard of Intensity of Periodic Motions. (Z.V.D.I., Vol. 77, No. 12, 25/3/33, p. 323.) (19.29/26615 Germany.)

A logarithmic standard is proposed with a unit designated " Pal " (Greek παλλειν to shake) analogous to the decibel or " Phon " of acoustics.

High and low frequency motions are distinguished as vibrations and oscillations, the former being perceived chiefly through the skin, the latter by the semicircular canal.

Two scales are discussed, but there appear to be greater difficulties in propounding a simple correspondence between the mechanical phenomena and the physiological sensation than in the case of sound perception.

Aerodromes—Landing and Housing

Grasses for Airports. (Sci. Am., Vol. 148, No. 3, March, 1933, p. 184.) (20.20/26616 U.S.A.)

The United States Department of Agriculture has planted 34 different grasses for observation as to suitability for planting on aerodromes to prevent formation of dust, mud, pools of rain water and to avoid erosion of soil by rain.

Airport Development. (N. Norman, J.R. Aer. Soc., Vol. 37, No. 265, Jan., 1933, pp. 1-34. See Abstract 24120.) (20.20/26617 Great Britain.)

A comprehensive statement is given of the principal requirements of a fully equipped first class airport. Most of the 28 illustrations refer to U.S.A. airports.

Areas of 200 acres and areas from 600 to nearly 1,000 acres have been reserved for development in some U.S.A. cities. Absence of landing surfaces with natural turf imposes surfaced runways from 400ft. to 500ft. wide by 2,500ft. long, four such runways giving eight landing directions spaced angularly at 45°. Buildings, equipment, handling, appliances, doors, lighting, fire protection, etc., are considered.

A discussion follows.

Lighting—Accumulators

Carbon Zinc Accumulator. (Z.V.D.I., Vol. 77, No. 2, 14/1/33, p. 55.) (21.00/26618 Germany.)

The negative electrode is a hollow zinc cylinder, the inside surface being covered with a preparation of cellulose and the inside space filled with graphite powder soaked in zinc iodide.

The positive electrode is a carbon rod running through the graphite powder. The whole is hermetically sealed.

In charging, the zinc iodide decomposes, the iodine being absorbed by the graphite and the zinc deposited on the cylinders.

During discharge the reverse process takes place, the discharging voltage falling from 1.2 to 1.1 volts per cell.

Aerodynamics and Hydrodynamics

Slow Motion of Fluid. (W. R. Dean, Phil. Mag., Vol. 15, No. 101, May, 1933, pp. 929-936.) (22.10/26619 Great Britain.)

A previous discussion of slow fluid motion past a plane barrier projecting into the fluid at right angles to the boundary is carried further by investigation of the pressure field near the projection.

The differential equation of motion is given in the simplest non-dimensional form as a bi-harmonic equation with the stream function as variable and a solution is adopted from the theory of elasticity.

The method is approximate and the solution fails at the edge of the projection. No really satisfactory experimental measurements of flow near the boundary are available, but the author makes such use of attempted measurements as is possible. The conclusion is reached that there is a finite slip near the edge.

(It is difficult to see how this conclusion can be drawn from the analysis. It might, of course, be included in the assumed boundary conditions.)

Resistance of Small Spheres in Air. (G. Monch, Phys. Zeit., Vol. 34, No. 2, 15/1/33, pp. 77-79.) (22.10/26620 Germany.)

Stokes' formulæ for the rate of fall of spheres in air require correction when the radius becomes small enough to affect the average value of impact pressure of the molecules in accordance with the kinetic theory of gases. A number of correction formulæ are examined and values of empirical constants are compared.

The experimental values found by the author lie very accurately on the curve given by Mattau's values of the coefficient and are 2 or 3 per cent. above the curve given by Millikan's coefficient, which apparently would change the latter's value of the charge of an electron in the same proportion.

Seven references.

Resistance of Small Spheres in a Viscous Fluid. (E. Wasser, Phys. Zeit., Vol. 34, No. 7, 1/4/33, pp. 257-278.) (22.10/26621 Germany.)

A critical review of the subject is carried out. The formula given by Stokes (1851) has been the subject of very numerous mathematical and experimental investigations both for steady and alternating motion. When the diameter is no longer large compared with the maximum free path, Brownian movements begin to appear and an excursion into the kinetic theory of gases becomes necessary. Numerous empirical and semi-empirical formulæ are quoted and discussed.

Applications of experimental results are shown graphically and confirm the accuracy of the equations within certain limits, outside which interpretation of the results becomes more difficult.

Important applications are considered.

Eighty references.

Separation by Settling of Suspended Particles under Gravity. (L. Schiller and A. Naumann, Z.V.D.I., Vol. 77, No. 12, 25/3/33, pp. 318-320.) (22.10/26622 Germany.)

The settling of small particles suspended in a fluid is applied as an industrial process, the basis of which is the resistance of bodies in slow motion. The formulæ given by Stokes for the fall of small spheres with modification by Oseen and Goldstein are compared with experiments.

Numerical values of non-dimensional parameters are tabulated and shown graphically as unicursal curves. Recent determinations of viscosity and density of air and water as functions of temperature are given graphically.

Heat Transference in Free Convection. II. Solution of the Boundary Layer Equation in Steady Motion. (R. Hermann, Phys. Zeit., Vol. 34, No. 5, 1/3/33, pp. 211-214.) (22.10/26623 Germany.)

The author introduces Grashof's parameter $gl^3\beta\vartheta/\gamma^2$ (β coefficient of thermal expansion) in a transformation of Boussinesq's equations. A method of approximate solution in the neighbourhood of a horizontal circular cylinder is indicated, and numerical tables are given. Observed temperatures are plotted for a particular value of κ/γ and give a satisfactory fit. As four arbitrary coefficients are introduced, this is not surprising.

Twelve references.

Speed of Ascent of Air Bubbles in Liquids. (T. Bryn, Forschung, Vol. 4, No. 1, Jan.-Feb., 1933, pp. 27-30.) (22.10/26624 Germany.)

Observations were made with small, medium and large bubbles in liquids of various viscosities. The rate of ascent of large bubbles is governed entirely by the Laplace coefficient being independent of the viscosity of the liquid.

The ascent of small bubbles is affected principally by conditions in the surface of the bubble, *i.e.*, how far and at what rate fresh liquid enters the surface. Under certain conditions a small spherical bubble may have considerably less resistance than a solid of equal dimensions.

Application of the Principle of Momentum in Hydrodynamics. (W. Müller, Ann. d. Phys., Vol. 16, No. 5, March, 1933, pp. 489-512.) (22.10/26625 Germany.)

The expression "Impulssatz," translated literally "momentum theorem," usually refers to a special aerodynamical application of the principle of momentum to determine the lift on a wing.

The hydrodynamical equations are developed in a vector notation which is not always self-consistent, with applications to turbine blades, wings, airscrews and plates with rotation as well as translation.

Loss of Air Pressure in Granular Layers. (W. Barth and W. Esser, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 82-86.) (22.10/26026 Germany.)

A sectioned sketch shows the arrangement of the test apparatus. A current of air passes through a measured depth of granulated material and the pressure drop is observed.

On plotting resistance coefficients against Reynolds number a series of unicursal curves is obtained lying in a narrow belt. The functional relation between the curves and the size of the grains is not very clear.

Comparison of experimental results of different authors gives a similar result.

Ten references.

Recent Results in the Investigation of Turbulence. (L. Prandtl, Z.V.D.I., Vol. 77, No. 5, 4/2/33, pp. 105-114.) (22.10/26627 Germany.)

After a recapitulation of his own analogy between the movement of eddying masses carrying momentum along mean paths and the movement of molecules in the kinetic theory of gases, the author proceeds to discuss Nikuradse's results for rough tubes.

The well-known v. Kármán relations between distance from the wall and velocity involving 1/7th root of the former, at higher Reynolds numbers the 1/8th and 1/9th roots, is generalised in a form of a logarithmic expression, which contains all these approximations as particular cases.

The analogy with the convection of heat is considered, and reference is made to G. I. Taylor's result that the analogy holds good when the lines of vorticity are parallel to the streamlines and fails when they are transverse which leads to

a modification of the definitions, so that eddy motion is subdivided into two component kinds, according as the general vorticity is parallel to or transverse to the streamlines. (This amounts to a very considerable, if not a fundamental, change in the author's original position.)

The artificial roughening of the walls introduces a new geometrical parameter by means of which the results for all amplitudes of roughness in relation to the tube diameter, are reduced to a unicursal curve which, however, still involves several empirical coefficients.

A considerable unification of experimental work has been attained, but the subject remains semi-empirical.

Thirty-eight references.

Contribution to Theory of Turbulent Flow. (F. Magyar and F. Kraemar, Phys. Zeit., Vol. 34, No. 6, 15/3/33, pp. 241-245.) (22.10/26628 Germany.)

The authors suggest that the elimination of the pressure and potential forces by cross differentiation (forming the curl) of the equations of fluid motion yields the form of the equations most amenable to analysis. The introduction of a stream function in two-dimensional flow gives a formal simplification, but this is not considered to be more tractable. Simplifying assumptions are made and a form of solution is assumed, and the corresponding disturbance of steady flow is shown graphically and resembles at the boundary a result given by Richardson and Taylor.

No definite result is obtained, but the point of view may indicate a suitable line of attack.

Heat Transference from a Horizontal Plate to Boiling Water. (M. Jakob and W. Linke, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 75-81.) (22.2/6.72/26629 Germany.)

The electric heating apparatus is described, with three sketches showing position of thermo couples.

A characteristic curve of vertical temperature shows a drop from 109°C. at the hot plate to 101°C. at 0.2 cm. above it, 100.5°C. at 1 cm. and 100.4°C. at 6 cm. (on the water surface). The steam above the water surface is at 100°C. The rate of heat transference is H.19,300 cal./m.^{2}h. Other characteristic curves show a coefficient of heat transference as a function of hot plate temperature.

The observed mechanism of transference was the formation of steam bubbles rising in well-defined columns from more or less permanent "hot spots." The number of columns was roughly in proportion with the rate of heat transference.

The transference plotted against plate temperature on logarithmic scales is nearly linear from $H=20$ to $H=10^5$, and thereafter there is a sharp fall in the relative temperature increase required.

Non-dimensional representation is applied, Nusselt's, Grasshof's and Prandtl's parameters are introduced and various empirical expressions are fitted to the experimental curves.

A wide range of experimental determination of heat transference by natural correction from neutral and horizontal cylinders, planes, cubes and spheres, lies along a unicursal curve with little scattering except in the lower range.

Twelve references.

Heat Transference in Flow through Pipes. (E. Hofmann, Phys. Zeit., Vol. 34, No. 5, 1/3/33, pp. 208-211.) (22.2/6.72/26630 Germany.)

The introduction of both Péclet's and Reynolds' parameter is required in comparing experimental results on a non-dimensional basis.

A large number of experimental results is assembled in a graphical chart representing empirical equations of a usual type.

Eight references.

Spiral Flow of Fluids in Pipes. (K. Schuster, Werft-Reederei-Hafen, No. 3, 1/2/33, pp. 36-37.) (22.2/26631 Germany.)

Eight types of industrial gas conduits are sketched with diagrammatic representations of flow. A photograph shows the pitch of the spiral, as marked by a thin strip of indicating fluid. Resistances are shown graphically as a function of flow speed.

Experiments on Flow Loss in Bent Pipes. (W. Spalding, Z.V.D.I., Vol. 77, No. 6, 11/2/33, pp. 143-148.) (22.2/26632 Germany.)

Flow through a number of bends at angles from 45° to 135° was investigated in the hydrodynamic laboratory of Danzig Technical High School—previous results of Nippert (V.D.I. Research Publication No. 320) were extended. It was generally found that the losses in the bend could be reduced by increasing slightly the cross section of the pipe at the bend.

Viscous Fluid Motion through Pipes with Cores. (N. A. V. Piercy, M. S. Hooper and H. F. Winny, Phil. Mag., No. 99, March, 1933, pp. 647-676.) (22.2/26633 Great Britain.)

Expressions are worked out for steady flow, in "slow" motion by the methods of rational hydrodynamics.

Experimental results for co-axial circular cylinders are in satisfactory agreement below the critical velocity.

Axial flow between confocal elliptical cylinders is also discussed mathematically. Critical speeds were observed experimentally, and a number of results are given graphically and in tables.

The extreme sensitivity of the equilibrium to eccentricity of the cylinders may explain the comparative failure of previous experiments.

Coefficients of resistance in turbulent flow were determined experimentally and extensive data are given in tables and graphically.

Critical Velocity in Pipes. (A. H. Gibson, Phil. Mag., Vol. 15, No. 99, March, 1933, pp. 637-647.) (22.2/26634 Great Britain.)

An extension of Reynolds' well-known experiment is described. The coloured filament is adjusted so as to flow parallel to the axis at different radial distances. The critical velocity is shown graphically as a function of the radial distance.

The interpretation of the experimental work is not clear. In particular the last paragraph revives the old fallacy that dynamical similitude can be affected by the choice of moving axes in contradiction with Newtonian Mechanics.

It is suggested that the radial rate of variation of energy is important.

Flow in Nozzles and Diaphragms at Small Reynolds Numbers. (M. Hansen, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 64-66.) (22.2/26635 Germany.)

Experimental values of the discharge coefficient are shown graphically for different nozzle shapes.

The desirable quality of a constant discharge coefficient, down to the lowest possible Reynolds, appears to be associated with a sharp edge at the minimum diameter.

Four references.

Flow of Water in a Fine Annular Clearance between Coaxial Cylinders, with Rotation of the Inner Cylinder. (R. J. Cornish, Proc. Roy. Soc., Vol. 140, No. A.840, 1/4/33, pp. 227-240.) (22.2/26636 Great Britain.)

The dimensions of the annular cylindrical clearance were:—

	Mean dia.	Radial depths.	Axial lengths.
Apparatus I	6	0.0107 to 0.0176	15 cm.
Apparatus II	10	0.0233	28 cm.

The inner cylinder had a range of angular speeds from 0-2,000 r.p.m.

Below the critical velocity the terms in the hydrodynamical equations corresponding to axial and co-axial flows are separable, the axial flow is independent only on the pressure gradient and independent of the rotation.

The torque does not appear to have been measured, but the observed critical angular velocity with decreasing axial velocity approaches an asymptotic value in line with G. I. Taylor's experiments, to which reference is made.

Since dynamical similitude depends on both radii and on angular and axial speed, these four quantities must appear in appropriate non-dimensional parameters, of which a large variety may be formed.

Four graphical representations are given of relations between sets of three such non-dimensional parameters, the critical axial velocity appearing as a singular line, on a contoured surface.

A number of empirical expressions are quoted for flow above the critical speed, but beyond having non-dimensional parameters and thus satisfying dimensional requirements, they are purely empirical.

The results have applications to pressure lubrication.

Seven references.

Theory of Air Flow. (N. A. V. Piercy, Airc. Eng., Vol. 5, No. 47, Jan., 1933, pp. 14-16.) (22.4/26637 Great Britain.)

The elementary equations of viscous fluid motion are derived in a manner which is directed to the elucidation of difficulties met with in the study of standard text books.

Reduction of Resistance to Flow by Guide Vanes. (K. Frey, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 67-74.) (22.4/26638 Germany.)

The types of flow modified by vanes are shown in 40 sketches and include guide vanes in channels, single and double slots for wing profiles and single, double and triple vanes of the Townend ring type.

Resistance coefficients are plotted against the Reynolds number. The phenomena involved are complex and obscure, as appears in the discussion of the results in their application to design, but the extensive range of numerical values facilitates the selection of a suitable arrangement, within the range of the experiments.

Fifteen references.

Air Pressure on a Cone Moving at High Speed. (G. I. Taylor and J. W. Maccoll, Proc. Roy. Soc., Vol. 139, No. A.838, 1/2/33, pp. 278-311.) (22.4/26639 Great Britain.)

A solid right circular cone moves in air at speed above that of sound. The appropriate hydrodynamical equations are developed on the assumption that pressure, density and velocity in the neighbourhood of the conical surface are functions of the angular polar co-ordinate only. The velocity field is, therefore, irrotational. The relations are taken as adiabatic so that temperature need not appear explicitly.

The differential equation of motion thus obtained is non-linear, involving the second derivative of the axial velocity and the first power, square and cube of the

first derivative with respect to the cone angle. Taking the cone angle as initial polar co-ordinate, the initial velocity = zero, the equation is integrated numerically step by step.

Meyer's equations, applied numerically, give the pressure distribution, including the discontinuity across a shock wave.

The projectile velocity at which a shock wave travels with the point of the projectile is greater than the speed of sound in air by a factor which increases with the cone angle.

Pressures are calculated and show comprehensive agreement with wind channel resistance measurement and with results obtained for photographs of waves of compression.

Von Kármán's approximate solution is found to be in satisfactory agreement for small cone angles with discrepancies increasing as the cone angle increases.

Measurement of Gas Flow with Nozzles and Orifices Operating at Small Reynolds Numbers. (H. G. Giese, Forschung, Vol. 4, No. 1, Jan.-Feb., 1933, pp. 11-20.) (22.5/26640 Germany.)

The range of Reynolds number was from $R=8$ to $R=50{,}000$. There is a general decrease in the flow coefficient as R decreases below 100. Above this value rounded nozzles show a continuous increase and nozzles with sharp edges decrease with increasing R. By suitably rounding off the orifice plate a substantially constant coefficient was obtained from $R=600$ to 110,000.

Influence of Viscosity on the Coefficient of Flow through Throttles. (F. Kretzschmer, Forschung, Vol. 4, No. 2, March-April, 1933, pp. 93-95.) (22.5/26641 Germany.)

Empirical formulæ are given a non-dimensional form. Results are plotted against Reynolds number for different throttling ratios. Similarity is found with the form of the empirical expression for resistance in a constricted pipe. Beyond a certain value of the Reynolds number the term involving viscosity becomes unimportant.

An Adjustable Orifice for Measurement of Gas or Air Delivery. (Z.V.D.I., Vol. 77, No. 6, 11/2/33, pp. 155-156.) (22.5/26642 Germany.)

The adjustable orifice, resembling a photographic shutter, was calibrated against the standard V.D.I. throttle plate and showed variations not exceeding ± 1.5 per cent. over the range of opening.

Materials—Elasticity and Plasticity

Diagonal Gyrometer in Chladni Figures. (R. C. Colwell, J. Frank. Inst., Vol. 215, No. 2, Feb., 1933, pp. 169-177.) (23.0/13.81/26643 U.S.A.)

The usual solution is considered in forms which contain a linear factor corresponding to a diagonal.

Numerous experimental figures are reproduced and discussed numerically in reference to the appropriate forms of the solution.

Vibrations of a Chladni Plate. (R. C. Colwell, Phil. Mag., Vol. 15, No. 97, Feb., 1933, pp. 317-324.) (23.0/13.81/26644 Great Britain.)

Rayleigh's differential equation of motion is written down. Ritz's methods of approximate solutions are discussed.

First and second approximations are obtained and compared graphically and experimental figures of similar types are reproduced.

Temperature Coefficient of Elastic Constants. (G. H. Keulegan and M. R. Houseman, Bur. Stan. J. Res., Vol. 10, No. 3, March, 1933, pp. 289-320.) (23.0/26645 U.S.A.)

Young's modulus and the modulus of rigidity were determined for a range of temperatures from $-50°$C. to $+50°$C. and are tabulated for forty-five specimens. Chromium, nickel, high carbon and silicon steels show variations in the modulus of rigidity from 12 to 21 per cent.; stainless steels from 9 to 35 per cent. The changes in Young's modulus are roughly half as great. Light and heavy alloys show much smaller variations.

Loops were obtained in the temperature strain diagrams under constant load, the lower branch corresponding to decreasing temperature.

Investigation of the Geometrical and Physical Conditions of Polished Surfaces. (G. Schmerwitz, Phys. Zeit., Vol. 34, No. 4, 15/2/33, pp. 145-158.) (23.10/26646 Germany.)

Small changes in the thickness of a body are difficult to measure directly. It is possible to estimate the magnitude of surface irregularities by comparing variations of radius of curvature of the surface. Using a special apparatus designed by Zeiss, the author has investigated in this manner a series of cylindrical and spherical bodies of approximately 2 mm. diameter, which had previously received the most careful polishing treatment. The wire showed the greatest departure from a circular contour; steel balls and especially glass balls showed a constant diameter to within .1μ. The author has been able to demonstrate some variation of surface contour with time. These variations amount to a few thousandth μ and are due to a form of Brownian movement of the surface layers.

Applications of the Theorem of Three Moments. (V. Belfield, Phil. Mag., No. 99, March, 1933, pp. 562-574.) (23.30/26647 Great Britain.)

Portal frames and T frames with rigid joints are reduced to equivalent continuous girders and stress problems solved by applications of the theorem of three moments. A neat application is made to the problem of a beam under simple loading.

Stability of a Framed Strut. (L. Seltenhammer, Sitzung-Berichte, Vol. 142, No. 1-2, 1933.) (23.30/26648 Austria.)

The bending moment is considered in both the principal planes of the section. The length of the frame is subdivided into an arbitrary number of panels, with a corresponding number of equations ($4m$).

The methods of finite differences are applied to shorten the extensive computations of step-by-step solutions.

Summations are obtained which give satisfactory approximations. Numerical results are tabulated and compared with those of other methods.

Struts. (R. Rodger, Flight, Vol. 25, No. 8, 23/2/33, pp. 178 f-g.) (23.30/26649 Great Britain.)

Southwell's strut formula has been transformed as a function of stress instead of load. A numerical table and graphical chart are given for rapid computation.

Bending of Grid Girders. (S. Timoshenko, Z.A.M.M., Vol. 13, No. 2, April, 1933, pp. 153-159.) (23.40/26650 Germany.)

Consideration is given to girders with equal parallel spars and stiffening cross-pieces.

Linear cross distributors of load are assumed from mid-point to mid-point of the cross-pieces, and a solution is obtained for the rib deflections in two elementary functions which are tabulated numerically.

Fourier expansions may be assumed for the elastic line, and the coefficients determined from the strains. General expressions are obtained and simplified for special cases.

The case of a single spar is first considered, and the method is generalised for multiple spars. A numerical example is worked out.

Experimental Determination of Forces and Moments in Statically Indeterminate Structures. (F. C. Lea, Phil. Mag., Vol. 15, No. 101, May, 1933, pp. 881-904.) (23.40/26651 Great Britain.)

The elementary principles of the method of minimum strain energy are discussed; Mannell's theorem of reciprocal displacements is illustrated by simple applications, and a method of obtaining moments from slopes and deflections is prescribed.

Principles of dynamical similitude are formulated, and experimental methods are described and applications to models are worked out. Comparisons between experiment and calculation show agreement close enough to give confidence in the method, notwithstanding difficulties arising from the lack of isotropy in timber structures.

Calculation of Stresses in Braced Frameworks. (R. V. Southwell, Proc. Roy. Soc., Vol. 139, No. A.839, 3/3/33, pp. 475-507.) (23.40/26652 Great Britain.)

Author's abstract:—Stress determination in frameworks has been developed mainly by graphical methods, and in consequence there has been a tendency to fix attention on problems in two dimensions. An alternative (analytical) method of treatment has been found useful in relation to the structural problems of aeronautics, which are largely three-dimensional; it has the further advantage that problems can be treated in a general manner, and solutions of wide applicability obtained.

An example is given in this paper; exact solutions can be found for a tabular framework (generally representative of a rigid airship hull, or of a fuselage of " monococque " construction) when definite (self-equilibrating) forces are specified as acting on the joints. This problem (on account of the high order of redundancy of the framework) would be quite intractable by conventional methods; but here no appeal is made to considerations of strain-energy, solutions being constructed by synthesis from " type solutions " which are fully investigated.

In the concluding section of the paper a procedure is described whereby its solutions may be extended to " pseudo-redundant " frameworks, in which some of the constituent members are incapable of sustaining compression. It is shown that the procedure will give sufficiently accurate results under the conditions which immediately precede failure—namely, when many such members have become inoperative.

Miscellaneous

Manœuvres of British Tank Brigade. (B. H. Liddell-Hart, Army Ordnance, Vol. 13, No. 76, Jan.-Feb., 1933, pp. 220-225.) (26653 U.S.A.)

A critique of the 1932 exercises gives details of the performances attained under the conditions of manœuvres.

Aerial Offensive in Maritime Warfare. (Lieut. Barjot, Rev. F. Aér. No. 42, Jan., 1933, pp. 61-90.) (26654 France.)

Serre (France) considers attack on enemy ships to be the principal object of an aerial offensive. Fioravanzo (Italy) gives greater importance to the demolition of the fleet base. The more restricted the theatre of war the more important the aerial offensive becomes. The author favours the latter view.

Naval—The "Deutschland." (Werft-Reederei-Hafen, No. 6, 15/3/33, pp. 85-86.) (26655 Germany.)

Development of design is discussed in reference to guns, directors, torpedoes, aircraft, spotting, under-water protection, and radius of action.

Two photographs of the "Deutschland" are reproduced.

Eleven references.

Animal Flight. (R. E. Snodgrass, J.R. Aer. Soc., Vol. 37, No. 266, Feb., 1933, pp. 113-144.) (26656 Great Britain.)

An analysis of insect wing structure and wing motion is based on information collected at the Bureau of Entomology, U.S.A. Dept. of Agriculture.

Numerous anatomical diagrams are reproduced.

Thirty-five references.

Time-Keeping. (F. Hope-Jones, J. Sci. Inst., Vol. 10, No. 2, Feb., 1933, pp. 43-49.) (26657 Great Britain.)

Application of an impulse to the second pendulum only once per half minute has increased the accuracy to within a few thousandths of a second, enabling the effects of the earth's rotation to be observed, while comparison with a quartz crystal control at the Bell Telephone Laboratories has brought out the effect of lunar motion of local gravity of the order of 1/5,000th second.

Pressure of Saturated Water Vapour from 100° *to* 374°. (N. S. Osborne and others, Bur. Stan. J. Res., Vol. 10, No. 2, Feb., 1933, pp. 155-188.) (26658 U.S.A.)

A careful account is given of the apparatus and accessories for providing and maintaining pure air-free water at desired temperature, and measuring the corresponding pressure. Comprehensive tables of results are expressed in various current units as well as in standard international units.

The error is estimated as not exceeding 0.03 per cent., except near the critical range where it may be greater.

The result should be a valuable check on existing steam tables.

Condensation and Evaporation—Recent Notions and Experiments Using Steam. (M. Jakob, Z.V.D.I., Vol. 76, No. 48, 26/11/32, pp. 1161-1170.) (26659 Germany.)

Read at the V.D.I. Scientific Conference, Berlin, October, 1932.

Condensation may form films or drops of fluid, the latter accompanied by greater heat transfer than the former. The formation of drops is determined mainly by the magnitude and direction of the steam's velocity, but surface tension also plays a part.

The rapidity of evaporation at a hot surface is mainly governed by the stirring action of the superheated steam.

By control of the motion of the water it was found possible to obtain a very high rate of heat transfer (approximately 13,000 k.cal./m.^{2}/h.°C.).

Nineteen figures, twenty-three references. The article has been translated.

Investigation on a Differential Transmission Dynamometer. (W. Kautter, Ing. Arch., Vol. 4, No. 1, Feb., 1933, pp. 35-42.) (26660 Germany.)

The transmission dynamometer was designed for operation up to 1,500 r.p.m. under torques up to 5 kg.m. weight × 1 m. The efficiency was determined electrically by a modified Hopkinson test.

The friction torque loss amounts to less than 0.2 kg.m., and after calibration the instrument was reliable to within $\frac{1}{2}$ per cent.

It is cheaper and more robust than a torsion dynamometer of equivalent accuracy.

Six references.

SUMMARY OF THE SOCIETY'S ACTIVITIES

DECEMBER, 1932—DECEMBER, 1933

The following places on permanent record in the Journal the notices which have appeared in the Monthly Notices inset in the Journal, and so summarises the activities of the Society for the year. Activities not reported in this summary will be given in the Annual Report of the Council.

Council

The following is the full Council for 1933-1934:—

President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Past-President:

Colonel the Master of Sempill, A.F.C., F.R.Ae.S.

Vice-Presidents:

Prof. L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.
Air Marshal Sir H. R. M. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C., F.R.Ae.S.

Council:

Captain P. D. Acland.
Major J. S. Buchanan, O.B.E., A.M.I.Mech.E., F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., B.A., F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. W. S. Farren, M.B.E., F.R.Ae.S., M.I.Ae.E.
Mr. A. H. Hall, C.B.E., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Captain A. G. Lamplugh, F.R.G.S., M.I.Ae.E., F.R.Ae.S.
Mr. M. Langley, A.M.I.Ae.E., A.M.Inst.N.A.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. R. K. Pierson, M.B.E., B.Sc., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. D. R. Pye, M.A., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.Sc., F.R.Ae.S.
Lieut.-Col F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.
Sir J. D. Siddeley, C.B.E., F.R.Ae.S.
Mr. F. Sigrist, M.B.E., F.R.Ae.S.
Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.I.Ae.E., M.P.
Prof. R. V. Southwell, M.A., F.R.S., F.R.Ae.S.

Hon. Treasurer:

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Solicitor:

Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Hon. Librarian:

Mr. J. E. Hodgson.

Hon. Accountant:
Mr. A. N. D. Smith, F.C.A.

Secretary and Editor:
Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Committees of Council

The following Committees of Council were appointed for 1933-1934:—

Grading Committee:

Captain F. S. Barnwell, Mr. R. A. Bruce, Major G. P. Bulman, Major F. A. Bumpus, Mr. W. S. Farren, Lieut.-Col. L. F. R. Fell, Mr. A. Gouge, Professor F. T. Hill, Mr. R. J. Mitchell, Mr. W. P. Savage, Colonel the Master of Sempill, Prof. R. V. Southwell and Dr. H. C. Watts.

Finance Committee:

Captain P. D. Acland, Mr. Griffith Brewer, Mr. E. C. Gordon England, Mr. C. R. Fairey, Professor F. T. Hill, Mr. J. E. Hodgson, Major D. H. Kennedy, Captain A. G. Lamplugh, Mr. John Lord, Mr. F. R. Simms, Mr. A. N. D. Smith, Mr. L. A. Wingfield.

Lectures Committee:

Prof. L. Bairstow, Major T. M. Barlow, Mr. M. L. Bramson, Major G. P. Bulman, Mr. R. S. Capon, Captain F. Entwistle, Mr. F. A. Foord, Mr. H. Glauert, Major F. M. Green, Captain G. T. R. Hill, Mr. H. B. Irving, Mr. M. Langley, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, Mr. S. Scott Hall and Mr. C. C. Walker.

Education and Examinations Committee:

Major T. M. Barlow, Prof. L. Bairstow, Mr. R. S. Capon, Mr. W. E. Dumbrill, Professor F. T. Hill, Prof. B. Melvill Jones, Mr. M. Langley, Mr. W. M. Page, Dr. N. A. V. Piercy, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. W. P. Savage, Mr. H. T. Tizard, Captain G. S. Wilkinson and Mr. L. A. Wingfield.

Medals and Awards Committee:

Major T. M. Barlow, Mr. Griffith Brewer, Air Marshal Sir H. R. M. Brooke-Popham, Major J. S. Buchanan, Mr. A. H. R. Fedden, Group Captain G. B. Hynes, Mr. W. O. Manning, Sir A. Verdon-Roe, Mr. G. R. Volkert, Mr. C. C. Walker, Mr. H. E. Wimperis, Mr. L. A. Wingfield and Mr. R. McKinnon Wood.

Joint Standing Committee with the S.B.A.C. and the Royal Aero Club:

Prof. L. Bairstow, Col. the Master of Sempill and Lieut.-Col. F. C. Shelmerdine.

Rules Sub-Committee:

Prof. L. Bairstow, Mr. Griffith Brewer, the Master of Sempill, Mr. A. H. Hall, Mr. W. O. Manning, Major D. H. Kennedy, Mr. L. A. Wingfield.

Ground Engineers' Committee:

Mr. E. C. Gordon England, Professor F. T. Hill, Major D. H. Kennedy, Mr. W. O. Manning, Major R. H. Mayo, Lieut.-Colonel H. W. S. Outram, Mr. R. K. Pierson, Colonel the Master of Sempill, Mr. C. C. Walker.

Amulree Committee:

Prof. L. Bairstow, Mr. Griffith Brewer, Mr. C. R. Fairey, Major D. H. Kennedy, the Master of Sempill, Mr. H. E. Wimperis.

REPRESENTATIVES ON OTHER BODIES.

British Engineering Standards Association Aircraft Committee: Major R. H. Mayo and Dr. H. C. Watts.

Advisory Council of the Science Museum: Colonel the Master of Sempill.

National Central Library: Mr. J. E. Hodgson.

Students' Section: Mr. C. H. Jackson (Honorary Secretary).

Association of Special Libraries and Information Bureaux: Mr. J. E. Hodgson.

Advisory Committee on Aeronautical Education of the Imperial College: Mr. C. R. Fairey.

B.E.S.A. Committee on Symbols and Abbreviations Used in Engineering: Major A. R. Low.

Lloyds Aviation Committee: Lieut.-Col. J. T. C. Moore-Brabazon.

British Corporation Register of Shipping and Aircraft, Aviation Committee: Colonel the Master of Sempill.

Seagrave Memorial Fund Committees: Mr. C. R. Fairey.

British Gliding Association: Council: Mr. W. O. Manning.
Technical Committee: Capt. J. L. Pritchard, Capt. F. T. Hill.

Aerodromes Advisory Board: Mr. C. R. Fairey and Colonel the Master of Sempill.

Air League of the British Empire: Mr. W. O. Manning.

Annual General Meeting

The Annual General Meeting of the Society was held on 28th March, 1933, in the Library of the Society.

Present:—Mr. C. R. Fairey, M.B.E., F.R.Ae.S. (President), in the chair. The Master of Sempill, A.F.C., F.R.Ae.S. (Past-President). *Council*: Messrs. Griffith Brewer, F. T. Hill, D. H. Kennedy (Hon. Treasurer), W. O. Manning and Lawrence A. Wingfield (Hon. Solicitor). *Ordinary Members*: Messrs. P. D. Acland, R. L. Carter, C. N. Colson, C. R. Elgie, P. P. Nazir and W. P. Savage. Captain J. Laurence Pritchard (Secretary). *Staff*: Miss Jarvis, Miss Todd and Miss Voice.

The Secretary read the notice convening the meeting.

In presenting the Annual Report and Accounts the President (Mr. C. R. Fairey) said: For the third year in succession I am privileged, as President, to review the work of the Society for the past year. The year 1932 has been a quiet one in many respects and there will not be any occasion for me to detain you at great length. I shall deal only with a few salient points from the report.

This is the 68th Annual Report of the Council that we are here to pass.

After 68 years of continuous existence the Society finds itself, I think, higher in prestige and in as strong a general position as it has ever enjoyed.

We number now over 1,300 members, of whom 860 are in the technical grades (this is not including Students). Our Journal has a larger circulation than ever before and our Lecture Programme in its variety and by the distinction of the people delivering the lectures is, I think, unique in the world.

It may interest you to know that in our long history there have been delivered no less than 562 lectures, the first of which was in June, 1866, on the subject of "Aerial Locomotion," by the late W. H. Wenham.

Our thanks are due to those responsible for arranging the lectures and to the distinguished people delivering them.

In the review last year I stated that 1931 was a year of great financial stringency and difficulty for the Society. This year has, I think, been even more difficult. The world depression has increased, and although the aircraft industry has held its own as well as or better than most industries, it is inevitable that we should feel the effect of this long period of economic stress. At the present time the uncertainty of the position, due to the long drawn out Disarmament Conference, coupled with the general tendency to make aviation the scapegoat of disarmament, is having an unsettling effect on the majority of the industry.

The military possibilities of aviation which were at first the cause of its strongest support, not only of the industry but of scientific research, are to-day the reason for the suspicion that is hampering, or seeking to hamper, every aspect of its development. People have not yet realised that these possibilities are inseparable from the very art of flying and that to attempt disarmament by limiting the progress of applied science is tackling the problem entirely at the wrong end.

It is remarkable in face of this situation and in the general unpopularity of aviation engendered by people whose knowledge of the subject is lamentable that the Society continues to progress.

Many scientific and engineering societies have, during 1932, lost membership, but the Royal Aeronautical Society has suffered far less severely than any. Out of a total of 868 technical members we have lost only ten. Many of those who have resigned have intimated their intention of resuming their membership when they get fresh employment in the industry. Despite the slight drop in membership there has been a slight increase in the annual subscriptions, due to the fact that membership has increased in the higher technical grades of the Society.

The membership of the branches has fallen off considerably, a result which is only to be expected as the membership of the branches depends almost directly upon the state of employment in the industry. Despite the difficulties with which the branches have been faced, however, their committees and secretaries have provided lectures for their members in a most remarkable way. The Council wish publicly to thank all those branch officials who have done so much and given so much of their time to arouse interest in aviation.

Last year I made reference to the inauguration of a series of Public Schools Lectures. These proved highly successful and the experiment was continued this year with still greater success. Since the time when these lectures were begun, eighteen months ago, 154 lectures have been delivered before approximately 35,000 people. These lectures have stimulated a demand for similar lectures outside the schools. The Council wish to thank all those members of the Society who have so willingly come forward and given much time and energy to the delivery of lectures on behalf of the Society. The Council are firmly of the opinion that this form of propaganda is a powerful factor towards making the country air-minded.

May I mention that these lectures were, in the first case, a suggestion of Mr. W. O. Manning, and by the same token I would like to remind you that Mr. Manning is now leaving the Council, under the new rule, after 14 years' continuous service. I would like to pay a public tribute to Mr. Manning's great services to the Royal Aeronautical Society. He has been one of the hardest workers on the Council, one most prolific in new suggestions, and one of the Society's most earnest supporters in every branch of its activities. I think you will agree with me in tendering to Mr. Manning, on behalf of the Society, our warmest thanks and our hopes that one day in the near future he will resume his useful work on the Council.

I should like to pay a tribute, too, to Mr. Griffith Brewer, a Vice-President of the Society, who, like Mr. Manning, is leaving the Council under the new rule. Mr. Griffith Brewer is perhaps one of the best known and best liked figures in aviation. He joined the Society as long ago as 1903, the year the

Wright Brothers first flew. Since 1912 he has served continuously on the Council and various Committees, a remarkable and unique record, I think, in the history of the Society. We very much regret his temporary break from the Council, though I am glad to say he is still serving on certain of the Council Committees, and we look forward to the time when he will be re-elected. The wisdom that comes of long experience is of high value and in Mr. Brewer we have a member of the Society who has had experiences in aviation which can only be described as unique.

In connection with the lectures the collection of slides owned by the Society has increased during the year, until there are now over 3,000 slides on aeronautical subjects from which to draw. This collection is one of the finest in the world. During the year an index of the slides was published. There are still many representative aircraft missing from the collection, however, and the Council hope that every member will bear this fact in mind and do his best to fill in any gaps.

I am able to announce another new development in the Society's activities. Some time ago I was sent for by Lord Amulree, then Secretary of State, who asked if the Society would consider the founding of some special award, not for scientific achievements as our present awards are given, but in recognition of great pioneering or record-breaking feats by pilots and for practical achievements generally. Lord Amulree asked for the co-operation of the Society to assist the Government in this matter.

Accordingly a Committee of the Council was formed, known as the Amulree Committee, and I am now able to announce that its plans have definitely matured. Two new medals, to be known as the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics, have been founded and will be awarded by this Committee in cases considered to be of sufficient importance. The Chairman of the Air League and the Chairman of the Royal Aero Club have been invited to join the Committee.

There are many activities which are held in abeyance on account of the lack of money. The Finance Committee, under the able guidance of Major Kennedy, the Honorary Treasurer, have steered the Society through difficult financial waters. The Society has been kept going by generous donations from the Air Ministry, the Society of British Aircraft Constructors and the Society of Motor Manufacturers and Traders, and the Council wish expressly to thank these bodies for the very great help which they have given. It is, indeed, due to their help that the Income and Expenditure Account of Aerial Science, Limited, shows an excess of income over expenditure. Without these donations there is an actual loss. That loss this year is £115, compared with £159 in 1931, £186 in 1930 and £862 in 1929. The loss is, in fact, the lowest for many years, a remarkable tribute in itself to the sound condition of the Society during a difficult year, and to the work of the Finance Committee.

In addition to the Honorary Treasurer there is one gentleman on the Finance Committee I should like specially to thank, Mr. Norman Smith, the Honorary Accountant. Mr. Smith is now in his sixth year of office. Last year he paid special attention to the Income Tax payable by the Society, and as a result of his representations to the Commissioners of Inland Revenue the Society's income is now tax free. Through Mr. Smith the Society were able to recover a considerable sum in Income Tax which had already been paid. I am sure we owe Mr. Smith a very deep debt of gratitude, for by his action he has added considerably to the income of the Society in the future. Of others who have given so much time and energy to the work of the Society I should like specifically to mention Mr. L. A. Wingfield, the Honorary Solicitor, who has so ably advised the Society on all legal questions, and Mr. J. E. Hodgson, the Honorary Librarian, whose unrivalled knowledge of the history of aviation has always been freely at the disposal of the Society in many ways. Many other members of the Society have

worked hard in its interests, and the Council would like publicly to thank all those members of committees who, busy though they are, have given up time to the work of the Society.

The Journal has continued to grow in influence through 1932, and it is significant that despite the depression over £1,300 was actually received in outside sales. The circulation of the Journal during the past five years has nearly doubled and the demand for it is steadily increasing.

While I was preparing notes for this meeting I received a letter from the Society of British Aircraft Constructors which will, I believe, prove of the utmost importance and benefit to the Society.

As many of you are aware, the policy of the Council for some years past has been to make the qualifications for Associate Fellowship and Associate Membership very real ones. Admittance to both grades is now very jealously guarded, and the Council are guided by a Grading Committee which represents all sides of the industry, the Air Ministry and the Universities. On January 1st this year new regulations came into force, following long and earnest labours of the Education and Examinations Committee.

The attitude of the Council has been very closely watched by the Society of British Aircraft Constructors, who are well aware that the chief technical men in the industry are members of the Society, and a few days ago I received the following important letter:—

THE SOCIETY OF BRITISH AIRCRAFT CONSTRUCTORS, LTD.
1, Albemarle Street, W.1,
21st March, 1933.

Dear Mr. Fairey,—The Society of British Aircraft Constructors have followed with great interest for some years the constant efforts which the Royal Aeronautical Society have made to make Associate Fellowship and Associate Membership of the Society very real qualifications.

They are satisfied now that each grade calls for such experience, training and technical knowledge that, other things being equal, an Associate Fellow or Associate Member of the Royal Aeronautical Society should be chosen for a post in the industry in preference to one not holding one of these qualifications.

Yours sincerely,
(Signed) (Sir) J. D. SIDDELEY, *Chairman*.

This is an unequivocal recognition of the standing of the Associate Fellow and Associate Member, and is a most gratifying acknowledgment of the high regard in which the Society is held by the controlling industrial body in British aviation. I am sure you will agree that we have every cause to congratulate ourselves on the receipt of this letter from the Chairman of the Society of British Aircraft Constructors—Sir John Siddeley.

Before closing this brief review I should like to say how much the Society owes to its staff. In Miss Jarvis, Miss Todd and Miss Voice, the Secretary has, I believe, a staff to which the Society has every cause to be grateful. The staff of the Society is among the smallest of any corresponding society. During the past five or six years the work of the Society has immensely increased, but there has been no corresponding increase in the staff. As an indication of the work done by the Secretary, Captain Pritchard, I may note that in addition to his normal work of running the Society, he has delivered during the past eighteen months thirty-six lectures to Public Schools and other bodies.

Finally, gentlemen, may I commend to your attention the urgent need for continuous practical support of the Society. As the accounts and the report show, we are holding our own, but only just, and that with the aid of generous donations. Moreover, we could not hold our own if we did not practise economies

and refrain from activities desirable in the interests of the Society and of the science it exists to foster.

Our Endowment Fund grows terribly slowly. To those who cannot contribute, do you know anybody who can and will you not use your personal persuasive powers with them? Do you not know anybody who should be a member of the Society in any grade, and is not? Or anybody who is a member and should be in a higher grade? We need money. We need increased membership. I submit that the Society more than justifies its existence and has a just claim for any support you can render it.

May I remind you that the annual general meeting gives an opportunity for members to put forward their views as to our past activities and future efforts. I hope anyone present will not hesitate to do so. The policy of the Council is governed by the wishes of the members and we welcome either advice or criticism and suggestions of any kind that can be of future benefit to the Society.

Mr. W. P. Savage suggested that the inclusion in the present accounts of recovered Income Tax over several years, together with the interest on the Endowment Fund, made the loss on the year's working (shown as £115 8s. 5d.) appear less than it actually was.

The Secretary stated that these items were always shown in that way by the Auditors.

Mr. Savage suggested that this might give members and others the impression that the Society was in a better financial position than was really the case.

The President pointed out that the question of the Endowment Fund was always very prominent and he did not think the form of the balance sheet would have any modifying effect.

In view of ten candidates having been nominated for the ten vacancies on the Council, no ballot was necessary, and the following were elected:—

Capt. P. D. Acland.	Major R. H. Mayo.
Major J. S. Buchanan.	*Lieut.-Col. F. C. Shelmerdine.
*Mr. A. H. Hall.	Sir J. D. Siddeley.
Capt. A. G. Lamplugh.	Mr. F. Sigrist.
*Mr. M. Langley.	Mr. O. E. Simmonds.

* Re-elected

On the proposal of Major Kennedy, seconded by Mr. Wingfield, Messrs. Price, Waterhouse and Co., were unanimously appointed Auditors for the ensuing year.

The Master of Sempill (Immediate Past-President) proposed a cordial vote of thanks to Mr. Fairey for his services as President. The Society heartily welcomed him again in the Presidential chair, and there was no doubt that the decision taken some time back to amend the rules regarding the Presidential term of office was very much to the interest of the Society. The speaker, in common with everyone else present, regarded Mr. Fairey as a friend, but that friendship would probably be lost if too much time were taken up in detailing his many services to the Society. Everyone knew that not only had the President put in a tremendous amount of hard work, but he had given support in a great many other directions, and it could be said without fear of contradiction that he had done more for the Society than had any previous President, and his successor would have a difficult task. He had read the letter from the Society of British Aircraft Constructors in a very off-hand manner, but for his influence with that body the desired result could not have come about.

Replying, the President said it was a very great privilege to be able to work for the Society. Colonel Sempill had not mentioned that most of the work of the Society which, owing to other demands upon his time, he (the President) had been unable to deal with, had been carried out by the Past-President himself. The President then paid a tribute to the loyal support accorded him by members of Council. The Society had been very well served with their Council, and he

was glad to know that those who were bound to retire by the new rules only did so temporarily.

Acknowledgment of Slides

The Council wish gratefully to acknowledge the following:—From Flight Lieut. R. E. H. Allen, slides of the autogiro controlling the traffic on Derby Day, 1932 (piloted by Flight Lieut. Allen); from Mr. Tilghman Richards, slides of 1913-1914 types of annular aeroplane (Cedric-Lee); from the Comper Aircraft Company, three slides and photographs of the Comper Swift; from the Westland Aircraft Works, slides of the Westland Wallace machine, including the machine used in the Mount Everest flight; from Messrs. Saunders-Roe, photographs and slides of amphibians; from Messrs. Pobjoy, Ltd., the loan of engine photographs for slides; from Messrs. Rolls-Royce, Ltd., twelve slides of the construction of Rolls-Royce engines.

Acknowledgments

The Council also wish to acknowledge the following:—From the Society of British Aircraft Constructors, a number of very useful books and papers; from Mr. T. B. Ringwood, several back numbers of the Journal; from Professor Ph. Theodorides and Professor A. F. Zahm, technical papers by them; from Mr. F. P. Walsh, a set of back numbers of the Journal; from Miss L. Chitty, a number of back issues of the Journal; from Mr. W. O. Manning, a set of Performance Charts of aeroplanes, seaplanes and ship aeroplanes of the war period and Abstracts from Aeronautical Patents for the years 1922-25, also a copy of the first edition of the Airworthiness Handbook for Civil Aircraft. Private Flying Machines and L'Exploration par Susées de la très haute atmosphere et la possibilité des voyages interplanetaires, par R. Esnault-Pelterie; from Mr. P. P. Nazir, two glass cases showing a sparrow hawk alighting and the spread wings of the black-headed gull and a prize carrier pigeon; from Mrs. Fullerton, a set of back numbers of the Journal; from Mr. R. F. R. Pierce, a copy of "The History of Aeronautics in Great Britain," and "Airsense," by W. O. Manning; from Lieut.-Col. T. O'B. Hubbard, a large number of air photographs taken by the R.F.C. on the Western Front; from Mr. J. L. Nayler, a number of photographs of wartime aircraft; from Dr. A. P. Thurston, Vol. I, No. 1, and Vol. I, No. 8, of the Institution of Aeronautical Engineers' Journal, and Vol. I, No. 2, and Vol. II, No. 4, and the Minutes of Proceedings, No. 16, of the Institution of Aeronautical Engineers; from Mr. G. E. Folkes, the Journal of the Society for 1918-1933; from Armstrong Siddeley, Ltd., photographs of the construction of their aero engines; from Mr. R. L. Howard-Flanders, copies of the Journal of the Society.

Awards

The following awards were made for the year 1933:—

Society's Gold Medal.—To Sir Richard Glazebrook, Fellow.

Society's Silver Medal.—To Mr. A. H. R. Fedden, Fellow, for his work on air-cooled engines, and particularly for his work in connection with the attaining of the height record by Captain C. F. Uwins; and to Mr. D. L. Hollis Williams, Associate Fellow, for his work on the design of the Fairey long-range monoplane.

British Silver Medal for Aeronautics.—To Flight Lieut. C. F. Uwins for reaching a world record height in a heavier-than-air craft of 43,976 feet on September 16th, 1932; and to Squadron Leader O. R. Gayford, D.F.C., R.A.F., and Flight Lieut. G. E. Nicholetts, A.F.C., R.A.F., who flew from Cranwell, England, to Walvis Bay, South Africa, non-stop, on February 6th-8th, 1933, a distance of 5,309 miles.

Elliott Memorial Prize.—To Sergeant Apprentice A. J. Mason, at Halton.

New Medals

Two new medals were founded during the year by the Society, the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics. These medals were founded following a request from Lord Amulree, when Secretary of State for Air, that the Royal Aeronautical Society should give some award for outstanding feats in aviation. A Committee was formed to consider the request of the Secretary of State, under the Chairmanship of the President of the Society, Mr. C. R. Fairey. After considerable discussion the Committee came to the following conclusions.

1. That a permanent Committee should be appointed to consider the awards of the medals. That this Committee should consist of six members of the Royal Aeronautical Society, and that the Chairman of the Royal Aero Club and the Air League should be invited to serve on it.
2. That the medals should be called the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics.
3. That the design of the Gold Medal should incorporate a portrait of Sir George Cayley and his first model aeroplane of 1804; that the design of the Silver Medal should incorporate the Henson and Stringfellow machines; that both medals should have on the reverse the peregrine and balloon emblem of the Society.
4. That the medals should be awarded for an achievement leading to advancement in aeronautical science.
5. That the award should be confined as far as possible to British Empire subjects, but other Nationals should not be excluded.
6. That the Committee should meet when their attention is drawn by the British Government to any meritorious achievement; when so directed by the Council; when their attention is drawn by the Royal Aero Club or the Air League to any meritorious achievement; or when their attention is drawn by any other recognised authority.

The expenses of founding these two important new medals were very heavy, and they were generously defrayed by the President, Mr. C. R. Fairey. To the President is due entirely the successful conclusions of the conversations with the Secretary of State for Air, which have resulted in two new air awards that will not only be highly prized but will commemorate the outstanding British aeronautical pioneers, Sir George Cayley, so rightly called the father of aeronautics, and John Stringfellow and W. S. Henson.

The awards of these medals will be for an *achievement* leading to an advancement in aeronautical science, and this point of view will be constantly borne in mind whenever awards of the medals are under consideration. The first two awards are detailed above.

Luncheon to Mrs. J. A. Mollison

A luncheon was given to Mrs. J. A. Mollison at the Park Lane Hotel, on Monday, December 19th, 1932, by the Royal Aeronautical Society, the Royal Aero Club and the Society of British Aircraft Constructors, in honour of her double record flight from London to Cape Town and back.

The President of the Society, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was in the chair, supported by Lord Gorell, Chairman of the Royal Aero Club, and Mr. Handley Page, representing the Society of British Aircraft Constructors.

Among those who attended the luncheon were the following:—

Lieutenant de Vaisseau Albertas (French Air Attaché); Flight Lieut. J. B. Allen, R.A.F.O.

Major T. M. Barlow, M.Sc., F.R.Ae.S.; Capt. R. R. Bentley; F. G. L. Bertram, Esq., C.B.E., M.A. (Deputy Director of Civil Aviation); Griffith Brewer, Esq., F.R.Ae.S.; Lieut.-Col. W. A. Bristow, M.I.E.E., M.I.A.E., F.R.Ae.S.; J. S. Buchanan, Esq., O.B.E., F.R.Ae.S. (Deputy Director of Technical Development); Major G. P. Bulman, O.B.E., F.R.Ae.S.; Flight Lieut. P. W. S. Bulman, M.C., A.F.C., A.F.R.Ae.S.; Major H. G. Brackley, D.S.O., D.S.C.; Air Marshal Sir H. R. M. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C.; E. C. Bowyer, Esq. (the Society of British Aircraft Constructors).

Major Corin; F. S. Cotton, Esq.; William Courtenay, Esq.

Capt. G. DeHavilland, O.B.E., A.F.C., F.R.Ae.S.; Flight Lieut. G. G. H. DuBoulay.

E. C. Gordon England, Esq., F.R.Ae.S. (Chairman, British Gliding Association); Capt. F. Entwistle, B.Sc.

A. H. R. Fedden, Esq., F.R.Ae.S.; Captain E. T. della Floresta, D.Sc. (Italian Air Attaché); Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E., F.R.Ae.S.

H. R. Gillman, Esq., A.F.R.Ae.S. (Secretary, the Society of British Aircraft Constructors); Lord Gorell, C.B.E., O.B.E., M.C., M.A. (Chairman of the Royal Aero Club); A. Gouge, Esq., F.R.Ae.S.; C. G. Grey, Esq. (Editor, *The Aeroplane*); Capt. the Hon. F. E. Guest, C.B.E., D.S.O., M.P.

Major F. B. Halford, F.R.Ae.S.; Squadron Leader H. L. J. Hinkler, A.F.C.; Captain W. L. Hope; Commander Norman D. Holbrook, V.C.

A. C. M. Jackaman, Esq., A.M.I.Ae.E.

Major D. H. Kennedy, O.B.E., F.R.Ae.S

Capt. A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E.; A. Limb, Esq.; Air Vice-Marshal A. M. Longmore, C.B., D.S.O.

Sir Francis K. McClean, A.F.C., A.F.R.Ae.S.; Capt. Norman Macmillan, M.C., A.F.C., A.F.R.Ae.S.; J. Stewart Mallam, Esq., F.C.A.; Major R. H. Mayo, O.B.E., F.R.Ae.S.; L. V. Meadowcroft, Esq.; J. A. Mollison, Esq.; Commander G. D. Murray, U.S.N. (American Air Attaché, Naval).

Colonel H. Nerinx (Belgian Military Attaché).

Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S.

F. Handley Page, Esq., C.B.E., F.R.Ae.S.; H. E. Perrin, Esq. (Secretary, Royal Aero Club); The Press Association; Capt. J. Laurence Pritchard, Hon.F.R.Ae.S. (Secretary, Royal Aeronautical Society); Capt. W. G. Pudney.

C. H. Roberts, Esq. (College of Aeronautical Engineering).

Air Chief Marshal Sir John M. Salmond, G.C.B., C.M.G., C.V.O., D.S.O., LL.D. (Chief of the Air Staff); Major M. F. Scanlon, D.S.M. (American Air Attaché, Military); Herr A. H. Van Scherpenberg (Secretary of the German Embassy); the Master of Sempill, A.F.C., F.R.Ae.S. (Immediate Past-President, Royal Aeronautical Society); Lieut.-Col F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S. (Director of Civil Aviation); G. C. Shepherd, Esq. (*The Times*); H. O. Short, Esq., F.R.Ae.S.; A. F. Sidgreaves, Esq., O.B.E. (Vice-President, Royal Aeronautical Society); G. C. Simpson, Esq., C.B., F.R.S., D.Sc., Hon.LL.D. (Director of the Meteorological Office); Stanley Spooner, Esq. (Editor, *Flight*); C. Stanhope Sprigg, Esq. (Editor, *Air and Airways*); Major Oliver Stewart (*The Morning Post*); B. Stevenson, Esq. (House Secretary, Royal Aero Club).

Major H. G. Travers, D.S.C.; Major C. C. Turner, A.F.R.Ae.S. (*The Daily Telegraph*); Dr. A. P. Thurston, F.R.Ae.S.

Capt. C. F. Uwins.

Sir A. Verdon-Roe, O.B.E., F.R.Ae.S.; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.; H. T. Vane, Esq., C.B.E.

Lord Wakefield of Hythe, C.B.E., Hon.LL.D., Hon.F.R.Ae.S.; C. C. Walker, Esq., F.R.Ae.S.; R. P. Wilson, Esq., C.B.E.; H. E. Wimperis, Esq., C.B.E., F.R.Ae.S. (Director of Scientific Research); Lawrence A. Wingfield, Esq., M.C., D.F.C. (Clerk to the Guild of Air Pilots and Air Navigators); J. L. R. Waplington, Esq. (Secretary, British Gliding Association); Squadron Leader Maurice Wright, A.F.C., A.F.R.Ae.S.

Luncheon to Squadron-Leader O. R. Gayford and Flight-Lt. G. E. Nicholetts

A luncheon was given to Squadron Leader O. R. Gayford, D.F.C., A.F.C., R.A.F., and Flight Lieut. G. E. Nicholetts, A.F.C., R.A.F., holders of the world's long range record of 5,309 miles, on Thursday, May 18th, 1933, by the Royal Aeronautical Society, the Royal Aero Club, the Society of British Aircraft Constructors and the Air League of the British Empire.

The President of the Society, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was in the chair, supported by Lord Gorell, Chairman of the Royal Aero Club, Mr. H. J. Thomas, Chairman of the Society of British Aircraft Constructors, and Major-General the Right Hon. J. E. B. Seely, C.B., C.M.G., P.C., D.S.O., Chairman of the Air League of the British Empire

Among those who attended the luncheon were the following:—

Captain P. D. Acland, Patrick Alexander, Esq., Hon.F.R.Ae.S., C. V. Allen, Esq., Dr. Auranawski.

Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., A. J. A. Wallace Barr, Esq., R. Blackburn, Esq., O.B.E., F.R.Ae.S., M.I.Ae.E., E. C. Bowyer, Esq., Major F. H. Bramwell, B.Sc., F.R.Ae.S., Sir Harry E. Brittain, K.B.E., C.M.G., LL.D., M.A., W. Broadbent, Esq., Major G. P. Bulman, O.B.E., F.R.Ae.S., Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I., R.A.F. (Ret.), H. Burroughes, Esq., A.F.R.Ae.S.

G. Calder, Esq., Central News, Ltd., Representative, Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S. (Secretary-General of the Air League of the British Empire), Flight Lieut. C. Clarkson, Squadron Leader S. N. Cole, A.F.R.Ae.S., R.A.F., Lieut. Comdr. C. N. Colson, A.R.Ae.S.I., R.N. (Retd.), William Courtenay, Esq.

Lieut.-Col. M. O. Darby, O.B.E., Squadron Leader C. J. W. Darwin, D.S.O., R.A.F., Wm. C. Devereux, Esq., A.F.R.Ae.S., Air Marshal H. C. T. Dowding, C.B., C.M.G. (Air Member for Supply and Research).

W. Lindsay Everard, Esq., M.P., Exchange Telegraph Co. Representative.

Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S., C. R. Field, Esq., Capt. A. G. Forsyth.

Air Commodore N. J. Gill, C.B.E., M.C., R.A.F., H. R. Gillman, Esq., A.F.R.Ae.S., Secretary of the Society of British Aircraft Constructors, Ltd., H. Gooding, Esq, Lord Gorell, C.B.E., O.B.E., M.C., M.A. (Chairman of the Royal Aero Club), A. Gouge, Esq., F.R.Ae.S., C. G. Grey, Esq. (Editor of *The Aeroplane*), Loel Guinness, Esq., M.P.

A. G. Hazell, Esq., Flight Lieut. L. Massey Hilton, D.F.C., A.F.C., A.R.Ae.S.I., Commander Norman D. Holbrook, V.C., R.N., D. L. Hollis-Williams, Esq., B.Sc., A.F.R.Ae.S., B. E. Holloway, Esq., C.B. (Director of Contracts, Air Ministry), J. Hopcraft, Esq., A.M.I.Ae.E.

A. C. M. Jackaman, Esq., A.M.I.Ae.E., L. W. Johnson, Esq., M.C., M.Met., M.I.A.E., A.F.R.Ae.S., F. H. Jones, Esq.

Major D. H. Kennedy, O.B.E., F.R.Ae.S., Admiral Mark Kerr, C.B., M.V.O., R.N.

John Lord, Esq., F.R.Ae.S.

Capt. N. Macmillan, M.C., A.F.C., A.F.R.Ae.S., Sir F. K. McClean, A.F.C., A.F.R.Ae.S., Major R. H. Mayo, O.B.E., F.R.Ae.S., H. H. Morris, Esq., F. W. Musson, Esq., B.A., A.F.C., A.F.R.Ae.S.

W. H. Nicholl, Esq., A.M.Inst.C.E., Capt. D. Nicolson, A.F.R.Ae.S.

F. Handley Page, Esq., C.B.E., F.R.Ae.S., George Parnall, Esq., Major R. E. Penny, O.B.E., F.R.Ae.S., H. E. Perrin, Esq. (Secretary of the Royal Aero Club), E. L. Pickles, Esq., O.B.E., A.F.R.Ae.S., N. A. V. Piercy, Esq., D.Sc., F.R.Ae.S., Ernest Pitman, Esq., Press Association Representative, Capt. J. Laurence Pritchard, Hon.F.R.Ae.S. (Secretary of the Royal Aeronautical Society).

Capt. H. C. Rawlings, D.S.O., R.N. (Director of the Naval Air Division, Admiralty), Reuters, Ltd., Representative, L. G. S. Reynolds, Esq., O.B.E., R. Rhodes, Esq., M.I.Ae.E., C. P. Robertson, Esq., M.B.E., F. Rowarth, Esq., N. Rowbotham, Esq., A.F.R.Ae.S., G. H. Russell, Esq.

Marshal of the Royal Air Force Sir John M. Salmond, G.C.B., C.M.G., C.V.O., D.S.O., LL.D., R.A.F., the Right Hon. Sir Philip A. G. D. Sassoon, Bart., G.C.B., C.M.G., M.P. (Under-Secretary of State for Air), Lord Herbert Scott, C.M.G., D.S.O., D.L., Major-General the Right Hon. J. E. B. Seely, C.B., C.M.G., P.C., D.S.O. (Chairman of the Air League of the British Empire), Sir John Shelley-Rolls, J.P., D.L., Lieut-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S., Director of Civil Aviation, H. O. Short, Esq., F.R.Ae.S., Sir J. D. Siddeley, K.B., F.R.Ae.S., A. E. L. Skinner, Esq., M.C., A. E. Slater, Esq., Sir Harold E. Snagge, K.B.E., M.A., J.P., Lieut.-Comdr. the Hon. J. M. Southwell, A.F.R.Ae.S., R.N., Stanley Spooner, Esq. (Editor of *Flight*), T. Stanhop Sprigg, Esq. (Editor of *Air and Airways*), Flight Lieut. G. H. Stainforth, A.F.C., R.A.F., Flight Lieut. C. S. Staniland, A.R.Ae.S.I., B. Stevenson, Esq. (House Secretary, Royal Aero Club), Major Oliver Stewart.

Herbert J. Thomas, Esq. (Chairman of the Society of British Aircraft Constructors), *The Times* Representative, Major C. C. Turner, A.F.R.Ae.S.

Capt. C. F. Uwins, A.F.R.Ae.S.

Harry Vandervell, Esq., Sir A. Verdon-Roe, O.B.E., F.R.Ae.S., M.I.Ae.E.

Lord Wakefield of Hythe, C.B.E., Hon.LL.D., Hon.F.R.Ae.S., C. C. Walker, Esq., F.R.Ae.S., J. L. R. Waplington, Esq. (Secretary of the British Gliding Association), Capt. G. S. Wilkinson, M.I.Mech.E., F.R.Ae.S., Lawrence A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I. (Clerk to the Guild of Air Pilots and Air Navigators), G. E. Woods-Humphery, Esq., Squadron Leader Maurice Wright, A.F.C., A.F.R.Ae.S.

R. F. Youngman, Esq., B.Sc.

Examinations

Examinations for Associate Fellowship and Associate Membership were held in the Offices of the Society on December 30th and 31st, 1932. The following satisfied the examiners in their respective subjects:—

ASSOCIATE FELLOWSHIP EXAMINATION.

Strength and Elasticity of Materials and Theory of Structures.—H. O. Baker, J. G. Brown, F. S. Dorabjee, J. Elston, R. R. Goodbody, K. C. Griggs, K. Hitchins, J. C. Hornby, C. H. Hunter, T. H. Jackson, J. A. Kelly, A. H. Martin, B. C. Puri, E. J. Riddle, E. H. Welch (First Place), W. Wilson.

Heat Engines.—J. G. Brown, J. Elston, S. C. Fairbairn, A. G. Gooch, R. R. Goodbody, K. C. Griggs, J. C. Hornby, W. A. K. Igoe, C. G. C. Leonard, W. P. Lewis, G. A. Mann, A. M. Martin, R. N. Mirza (First Place), B. C. Puri, E. J. Riddle, F. D. Sawyer, D. Stewart, P. N. Vincent, E. H. Welch, R. N. Wimshurst.

Chemistry and Metallurgy.—S. C. Fairbairn, A. G. Gooch (First Place), K. Hitchins, W. A. K. Igoe, T. H. Jackson, H. M. Kemp, R. E. Leete, R. N. Mirza, F. D. Sawyer, D. Stewart, R. N. Wimshurst.

Aerodynamics.—H. O. Baker, A. Davis, F. S. Kramer, R. E. Leete, J. van Hattum (First Place), W. Wilson.

Mathematics.—S. Shirodker.

Meteorology and Navigation.—F. S. Kramer.

ASSOCIATE MEMBERSHIP EXAMINATION.

Design of Aircraft.—C. G. Rogers, J. K. Wheatley (First Place), H. B. Wilkinson.

Air Transport.—H. B. Wilkinson (First Place).

Heat Engines.—R. N. Kathju, A. R. Osborn, H. W. R. A. Miller (First Place).

Chemistry and Metallurgy.—R N. Kathju (First Place), H. W. R. A. Miller.

Strength and Elasticity of Materials and Theory of Structures.—C. G. Rogers, J. K. Wheatley (First Place).

Forty-four candidates sat for the examinations—43 at the Offices of the Society and one under supervision (arranged by Professor A. Klemin) at the New York University. Of the 44 candidates, 27 passed in both subjects taken, 14 failed in one subject, and three failed in both subjects.

The examination papers were set and marked under the supervision of Professor F. T. Hill, of the Imperial College. The papers have been reprinted, and, together with 24 previous papers, may be obtained from the Office, price 1s., or 1s. 3d. post free.

The following is an extract from the Examiner's report: "One is left with the impression that a good many of the candidates taking Associate Fellowship have received a technical rather than a scientific training, and would have done themselves more credit in the Associate Membership papers."

The following candidates were successful in the examinations for Associate Fellowship and Associate Membership held on 24th April, 1933:—

ASSOCIATE FELLOWSHIP EXAMINATION.

Strength and Elasticity of Materials and Theory of Structures.—F. S. Dorabjee, C. H Hunter, J. A. Kelly, C. G. C. Leonard, W. P. Lewis, G. A. Mann, J. van Hattum.

Chemistry and Metallurgy.—F. S. Dorabjee, J. A. Kelly, P. N. Vincent.

Heat Engines.—C. H. Hunter, C. G. C. Leonard, W. P. Lewis, G. A. Mann, P. N. Vincent.

Aerodynamics.—J. van Hattum.

ASSOCIATE MEMBERSHIP EXAMINATION.

Design of Aircraft.—G. R. Irvine.

Air Transport.—G. R. Irvine.

The following candidates were successful in the examination for Associate Fellowship held on October 2nd, 1933:—

Strength of Materials and Theory of Structures.—A. Davies, H. M. Kemp, J. T. P. Mihailov.

Aerodynamics.—H. E. Sturge.

Chemistry and Metallurgy.—J. T. P. Mihailov.

B.Sc. Examination, University of London

One of the recommendations of the Education and Examinations Committee was that steps should be taken to increase the facilities for aeronautical education.

In November, 1932, a letter was sent to the University of London from which the following are extracts:—

"The President and Council of the Royal Aeronautical Society have had under consideration for the past two years the position of education in this country of aeronautical engineering. They wish to acknowledge the great help which the University of London has afforded in the rapidly developing subject of aeronautical engineering.

"The Council believe that the position has now reached a stage when a further step might with advantage be taken. In particular they have had under consideration the subject Mechanics of Fluids in the syllabus of the University and are strongly of the opinion that a revised syllabus for applied aerodynamics should be allowed as a whole subject in Group B of the B.Sc. engineering syllabus as an encouragement to aeronautical students."

In reply to the letter from the Council, the following letter was received from the Secretary to the Academic Registrar:—

"With reference to your letter of 21st November, 1932, regarding the inclusion of Aeronautics in the syllabus of the Mechanics of Fluids at the B.Sc.(Eng.) Final Examinations for Internal and External Students, I am directed to inform you that the Academic Council, after report from the Boards of Studies concerned, have amended the syllabus in Mechanics of Fluids at the B.Sc.(Eng.) Examination for Internal Students to read as follows:—

THE MECHANICS OF FLUIDS

(Two papers).

Candidates will be required to offer either Section A, Hydraulics, or Section B, Aerodynamics.

Section A.—Hydraulics.

Pressure on stationary surfaces and centre of pressure. Buoyancy. Steady and unsteady motion. Bernouili's theorem. Venturimeter. Distribution of pressure and velocity in free and forced vortices. Laws of flow through orifices, mouth-pieces and notches. Velocity of approach. Laws of fluid friction. Viscosity. Theory of physical dimensions applied to similar motions. The principle of dynamical similarity. Pressures on planes and bodies moving through a fluid. Resultant force and centre of pressure. Flow in pipes; frictional and other losses. Branched pipes. Flow in channels; ordinary form of channel.

River gauging; instruments and methods. Catchment areas; relation of rainfall and flow off ground. Storage and conveyance of water. Water supply and drainage. Impact of water on surfaces. Reaction of jets. Pelton wheel. Turbines and centrifugal pumps. Reciprocating pumps. Accumulators and intensifiers.

Section B.—Aerodynamics.

Airflow Theory and Experiment.—Relevant physical properties of the atmosphere. Laws of viscosity and the viscous stresses in two-dimensional flow. Aerodynamical applications of the Principle of similitude. Theory and practice of wind tunnel measurement; other experiments and important results. Theory and design of airscrews. Elements of potential flow. Single rectilinear vortex and vortex pair. Elements of Prandtl's aerofoil theory. Simple tunnel corrections. Boundary Layer and von Karman's theorem.

Aircraft Motion.—Forms of aircraft and choice of parts. Computation of drag. Equilibrium in steady rectilinear and circular flight. Speed range, useful load, rate of climb, ceiling. Prediction, testing and analysis of performance; Reduction to standard atmosphere. Simple manœuvres. Accelerometer reading and load factor. Nature of stability and disturbed aeroplane motion. Trim in relation to control and stability. Rolling moments and the dihedral angle. Autorotation. Full scale experiments.

This revised syllabus will come into force in 1935, but candidates may offer it in 1934 if they wish."

Elections

The following recommendations of the Grading Committee were approved by the Council:—

On 13th December, 1932:—

Fellow.—Frederick Charles Johansen.

Associate Fellow.—John Eustace Arthur Baldwin, George Francis Meager, George Panagiotis Tzannetakis.

Associate.—Biraja Madhab Gupta, Richard Humble, Clive Edmund Gordon Murray Waller (Australian Branch).

Student.—Montague Waddel Harvey, Frederick Charles Hentsch, Alan King Martin (Australian Branch), Frederick Norman Montague, Sven Christian Poulsen.

Companion.—William Garrow-Fisher (from Student), Herbert Gooding, Clement James Selden (from Student).

On 17th January, 1933:—

Fellows.—Herbert Alfred Mettam (from A.F.), Herbert Charles Henry Townend (from A.F.).

Associate Fellows.—James Valentine Connolly (from Associate, Australasian Branch), Wallace Charles Devereux.

Associate Member.—Reginald David Easton.

Associates.—The Marquis Hachisuka, Lee Cameron Lathrop Murray.

Students.—John William Thomas Brackett, Albert Dawson, Jack Hanson, Anthony Major Henniker, William James Stuart King-Smith, Dennis A. Letts, Jack Lobley, Ian Frank Meathrel, Darabshah P. Pavri, Hugh Guyer Small, Talbot Cecil Cochran Sweet-Escott, Kenneth Edmund Westover.

Companions.—William Lindsay Everard, Bernard William Galpin.

On 14th February, 1933:—

Associate Fellows.—Henry Herbert Gardner, Francis Olaf Thornton, Kenneth Franklin Tupper (from Companion).

Associate Members.—Ralph Alexander, William James Spencer Edmunds.

Associates.—John Vivian Holman, Cyril Arundel Penberthy (from Student).

Student.—Gerald Lawson Hulton Bott.

On 14th March, 1933:—

Fellow.—John Frederick Andrews Higgins.

Associate Fellows.—Reginald Sydney Brown, Fred S. Kramer, Reginald Herbert Schlotel, Theodore Michael Walker (from Student).

Associate Members.—Athol Rudolph Mayhill (from Companion), Henry William Rix Allen Miller.

Students.—Michel Alexander Benachi, Kenneth Blythe, John Hyde Mayo Canning, Saroj Kumar Das, Henry William Goodinge, Richard Winter Hase, Rio Nusservanji Mirza, Cedric Ormonde Vernon, Gerard Nunan Verver, Hendrik Adrian van de Wetering.

Companion.—John Fox.

On 11th April, 1933:—

Associate Fellows.—Reginald Sydney Brown, James Alexander Cracknell.

Associate Member.—Laurence John West.

Associates.—Dermott Lang Allen, Roger Francis Bulstrode (from Student), William Albert Crabbs (from Student).

Students.—James Arthur Bailey, Percival Howard Beattie, George Robert Charles Blowers, Wilfrid Beaumont Dixon Box, J. R. Crean, Edgar Alexander Wright.

On 9th May, 1933:—

Fellow.—Paul Ward Spencer Bulman (from Associate Fellow).

Member.—Frederic William Haig (from Associate Member—Australasian Branch).

Associate Fellows.—Syed Maksood Ally, Frank Radcliffe (from Associate).

Associate.—Stephen Richardson.

Students.—Rodolphe Burford Broadhurst, Robert Knight Page.

On 20th June, 1933:—

Fellows.—Francis Rodwell Banks (from Assoc. Fellow), James Douglas Kendall Restler.

Associate Fellows.—Henry Owen Baker (from Student), Graham Richards Dawbarn, Tulsi Dass Kumar (from Student), Frederick Alan Irving Muntz (from Associate), Harold Charles Pritchard, Juste Van Hattum, Henry Seddon Wildeblood (re-elected).

Associate Members.—Geoffrey Robert Irvine, Sidney Frederick Mitchell, Clifford Godfrey Rogers (from Associate).

Associates.—Stuart Heppolette King (from Student), Kawas Merji, Richard Courtenay Ilbert Pearse, Donald Teale Saville (Australasian Branch).

Students.—John Godsman Brown, Charles Clayton, Wallace Edward French, Terence Charles Harding, Arthur Henry Martin, Patrick Newton Vincent, J. Douglas Whitell, Robert Norman Wimshurst.

Companions.—Richard Meredith Alcock, John Edward Chorlton, Robert Frank Raymond Pierce (re-elected), Laurence M. Pinto (from Student).

On 19th September, 1933:—

Associate Fellows.—John William Kidston Allsop, Alan D'Arcy Hodgson, Thomas Jones, Cecil Arthur Rea.

Associate Members.—George Adams, Alfred Reginald Code, Arthur de Terrotte Nevill, Harry Povey, Raphael Chevallier Preston (from Associate), Kenneth Darleigh Salmon.

Associates.—Leslie Crocker, Alan Harper Curtis, George Llewhellin Griffiths, John Balfour Murray (from Student), Erik Blyth Nelson.

Students.—Frederick Connop Behenna, Leonard Bloomer, John Nevil Breeze, George Arthur Day, Donald William Loveys Fairbank, Ronald Oliver Farley (Australian Branch), John Stewart Kirkwood, Anthony Ives Hostage Lynch, George Hennal Mansell, Ram Angrah Prasad Misra, Frank Sidney Parry, Robert Paton, Nariman Rustomjee, Terence Archibald Tobit, Graham Wilson Topping, Alfred William Woolgar.

Companions.—Hurll Fontayne Chester (from Student), Charles Wilfred Crossland, H.R.H. the Maharaja of Jodhpur, Ivor McClure.

On 17th October, 1933:—

Associate Fellows.—Hans Belart, George Reuben Brooke, Richard Whitelegge O'Sullivan, Charles Harold Potts, Eustace Blewitt Robinson.

Associate.—Charles Edward Ward.

Students.—Habeeb Ahmed, Arthur Henry Davies, Denis John Milner Emerson, Edward George Fischeles, Charles Gerald Fisher, Alexander Jardine, Allan Thomas Oswald Liddell, Frederick Thomas Meacock, Peter Henry Milne-Milne, Leonard George Morris, Selwyn Cecil Perry, M. Pring-Rowe, Kaikhoshro Shapurji Saklatvala, Philip Garth Shott, Basil Robert Siminson, Arthur George Taylor, Leslie Ward.

Companions.—Robert Cecil Pierce, Edward Alfred Washer.

On 14th November, 1933:—

Associate Fellows.—Stuart Duncan Davies, Arthur Francis Scroggs, Herbert Frank Winny.

Associate.—Mobaulal Parmanaud Chablani.

Students.—John Diedrich Ahlers, John Wybrew Bond, Colin Calder Byar, M. G. Casey, Harry Davis, L. D. Dodswell, Firoze Sorabjee Dorabjee, Hugh Stanley Ellis, Reginald George Hurlstone Hector, Stephen George Hulbert, Lewis Larsen, Charles Hamilton Lilley, Paget McCormack, John Alexander Maurer, Stanley Ernest Nichols, William Ian Michael Nightingale, John Kenneth Redman, Ralph John Shire, John Vivian Stanbury, Edward Walter Sykes, Herbert David Barrett Taylor, John Brickwood Waite, John Lambert Watkinson.

Companion.—Percival Nesbit Willoughby.

Solicitor

The following is an extract from the Finance Committee Minutes approved by the Council at their meeting on Tuesday, June 20th, 1933:—

"The Committee RECOMMEND to Council that Mr. L. A. Wingfield, of Messrs. Wingfields, Halse and Trustram, 61, Cheapside, E.C.2, be appointed Solicitor to Aerial Science, Limited, and Aeronautical Trusts, Limited, on the understanding that he will attend meetings of the Council and the Finance Committee without remuneration.

"The Committee wishes to place on record and to draw the attention of the Council to their deep appreciation of the services Mr. L. A. Wingfield has rendered the Society during the years he has been Honorary Solicitor. During this time he has given his advice and time freely on many matters which have been of great benefit to the Society, including the completely revised Rules following the amalgamation with the Institution of Aeronautical Engineers, the formation of Aeronautical Trusts, Limited, the freeing of the Society from income

tax and other legal matters. The Committee feel that in Mr. Wingfield they have someone who has the real interests of the Society at heart. They are finally of the opinion that in fairness to Mr. Wingfield the title Honorary should be dropped."

Journal

Certain changes were made in the make-up of the Journal at the beginning of the year in order to bring the bound volume in greater conformity with the journals of other scientific societies. The title pages at the beginning of each monthly issue have been dropped and the index references contain only the page number and the volume number.

Corrections

The following corrections in the article by Mr. Lockspeiser, " A Simple Approach to the Wing Flutter Problem," should be made:—

Page 784, sub-section 3, para. 2: (*a*) $\dot{z}/\dot{V}$ should read $\dot{z}/V$. (*b*) $(z/\dot{V})\,V^2$ should read $(\dot{z}/V)\,V^2$. (*c*) zV should read $\dot{z}V$.

Page 787, line 9: $\ddot{Z}$ should read $\ddot{z}$.

Obituaries

The Council greatly regret to record the deaths of the following members of the Society:—

LAURENCE CHASE SHARMAN, *Companion.*

Commander Laurence Chase Sharman, R.N., a Companion of the Society, was one of the youngest officers attached to the Fleet Air Arm and had every prospect of a brilliant career. He entered the Navy in 1912 and served with distinction in the Navy in 1914-18. He was attached to the Fleet Air Arm in 1925 and served on the " Furious " and " Courageous " until he was transferred to the Admiralty in 1931.

Commander Sharman spoke at a number of lectures of the Society and showed a thorough grasp of the problems connected with naval flying. A man of great personal charm, his loss will be deeply felt by all those who had the privilege of knowing him.

A. P. HALL, *Student.*

A. P. Hall, a Student of the Society since 1931, was drowned while bathing. He was one who took a keen interest in aviation and his loss at such an early age is a severe blow to all who knew him.

MAJOR CHARLES KENNEDY COCHRAN-PATRICK, D.S.O., M.C., F.R.G.S., *Associate Fellow.*

Major Charles Kennedy Cochran-Patrick, who was killed in an accident to the aeroplane in which he was flying at the Baragwanath Aerodrome, Johannesburg, became an Associate Fellow of the Society in 1925.

Born in Edinburgh in 1896, he was the only son of Captain N. J. K. Cochran-Patrick and Mrs. Cochran-Patrick and was educated at Wellington College and Trinity College, Cambridge. In August, 1914, he entered Sandhurst and the following year was appointed to a commission in the Rifle Brigade. That year he learnt to fly on a Maurice Farman at Farnborough and took his certificate in April, 1915. In June he was seconded to the Royal Flying Corps and later posted to No. 1 Aircraft Depot, France. In May, 1916, he became Flight Commander with temporary rank of Captain and was posted to No. 70 Squadron in September.

In May, 1916, Cochran-Patrick was awarded the Military Cross. In April, 1917, he joined No. 25 Squadron, in July, 1917, No. 60 Squadron, and

in August he was awarded a bar to his M.C. for conspicuous gallantry in attacking hostile aircraft. He remained in command of No. 60 Squadron until the end of 1917, when he was awarded the D.S.O. and posted to the Eastern Training Brigade. At the beginning of 1918 he was posted to the Northern Training Brigade and eventually to the Air Ministry, Directorate of Training.

In July, 1919, Cochran-Patrick was promoted Major in the Rifle Brigade and shortly after he resigned his commission in the Royal Air Force. In civilian life he rapidly became famous for his air survey work. With Mr. Ronald Kemp he carried out the remarkable survey of the Irrawaddy Delta. He followed it with a mineralogical survey of the Belgian Congo border of Rhodesia, a survey of the irrigated areas north of Baghdad, and afterwards joined the Aircraft Operating Co. of South Africa.

In his comparatively short life Major Cochran-Patrick did as much to advance the cause of aviation as any man. He was a man who never spared himself any personal hardship to get a job done, a man of untiring energy and courage, who had a keen vision of the possibilities and future of aviation. He is a genuine loss to aviation and all that it means.

SIR EDWARD MANVILLE, J.P., *Founder Member.*

Sir Edward Manville, J.P., who was a Founder Member of the Society in 1911, died on March 17th, 1933, at the age of 70. He was always keenly interested in aviation and foresaw the change it would bring in world affairs. He was active in his support of the Society during difficult times and up to the day of his death remained one of its most enthusiastic supporters.

Lectures

The following lectures were read before the Society in 1933:—

January 12th.—" Airship Development Abroad," by Squadron Leader R. S. Booth, A.F.C.

January 26th.—" Human Limits in Flying," by Wing Commander G. S. Marshall, O.B.E., M.R.C.S.

February 2nd.—" The Operation of Aircraft Over Tropical Routes," by Mr. A. Plesman, Director of the Royal Dutch Air Lines.

February 16th.—" Cloud Formation with Reference to Up and Down Currents for Gliding," by Sir Gilbert T. Walker, C.S.I., F.R.A.S., F.R.S.

March 7th.—" Some Notes and Observations on Petrol and Diesel Engines," by Mr. H. R. Ricardo, B.A., F.R.S., F.R.Ae.S.

March 9th.—" Engine Cooling Research," by Mr. R. McKinnon Wood, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.

April 6th.—" Lessons of the Do.X," by Dr. C. Dornier.

April 27th.—" Seaplane Research," by Mr. H. M. Garner, M.A., F.R.Ae.S.

May 30th.—Twenty-first Wilbur Wright Memorial Lecture, by Colonel F. P. Lahm, Air Corps, U.S. Army, on " Training the Airplane Pilot."

October 12th.—" Air Traffic Control," by Major R. H. S. Mealing, A.R.Ae.S.I.

November 2nd.—" Variable Pitch Airscrews and Variable Gears," by Mr. W. G. Jennings, B.Sc.

November 16th.—" The Stiffness of Aeroplane Wings," by Mr. H. Roxbee Cox, Ph.D., D.I.C., A.F.R.Ae.S.

November 30th.—" Tail Buffeting," by Dr. W. J. Duncan.

December 7th.—" Possible Future Development of Aircraft Engines," by Mr. A. H. R. Fedden, M.B.E., F.R.Ae.S.

December 14th.—" Light Alloys for Aeronautical Purposes, with Special Reference to Magnesium," by Dr. L. Aitchison.

An Informal Debate was held on January 16th, when the following motion was proposed:—

"Civil Aviation differs from Military Aviation and should be treated accordingly."

Wilbur Wright Memorial Lecture

The Twenty-first Wilbur Wright Memorial Lecture was delivered on May 30th, 1933, by Colonel F. P. Lahm, Air Corps, U.S. Army, entitled "Training the Airplane Pilot." The lecture was followed by the Annual Council Dinner. Before the lecture was given the various medals and prizes which have been awarded during the year were presented. The report of the lecture and the Annual Council Dinner is given in pages 913-943.

The following is a list of the principal Lectures before the Branches:—

January 19th.—Lecture before the Yeovil Branch, by Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S., on "American Aviation Progress."

February 16th.—Lecture before the Yeovil Branch, by Major G. P. Bulman, O.B.E., F.R.Ae.S., on "Aero Engine Development."

February 24th.—Lecture before the Gloucester and Cheltenham Branch, by Captain C. H. Latimer Needham, M.Sc., F.R.Ae.S., on "The Conquest of Soaring Flight."

March 2nd.—Lecture before the Yeovil Branch, "Aircraft Armament Installations," by Squadron Leader C. Crawford, R.A.F.

March 16th.—Lecture before the Yeovil Branch, by Mr. Sammons, on "Petter Oil Engines."

October 5th.—Lecture before the Gloucester and Cheltenham Branch, by Captain J. Laurence Pritchard, Hon.F.R.Ae.S., on "Seaplane and Flying Boat Development."

October 10th.—Lecture before the Manchester Branch, by Squadron Leader O. R. Gayford, D.F.C., A.F.C., on "The World's Long Distance Record."

October 19th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. H. M. Garner, F.R.Ae.S., on "Experimental Work on Seaplanes."

October 19th.—Lecture before the Yeovil Branch, by Colonel L. V. Stewart Blacker, O.B.E., F.R.G.S., on "The Mount Everest Flights."

November 2nd.—Lecture before the Gloucester and Cheltenham Branch, by Mr. G. H. Dowty, M.I.Ae.E., on "Aircraft Wheel Brakes."

November 2nd.—Lecture before the Yeovil Branch, on "Press Work." Paper prepared by E. Bliss and Co., Co. and read by Mr. Gibson.

November 16th.—Lecture before the Yeovil Branch, on "The Developments of Oil Engines," by Mr. Dicksee, of the Associated Equipment Company.

November 21st.—Lecture before the Manchester Branch, on "Flying Boats," by a member of the staff of Messrs. Short Bros., Ltd.

November 30th.—Lecture before the Yeovil Branch, by Mr. J. C. Jennings, on "An Insight into Petroleum."

November 30th.—Lecture before the Gloucester and Cheltenham Branch, by Mr. Hayton, on "Heat Treatments."

December 7th.—Lecture before the Manchester Branch, by Senor Juan de la Cierva, on "The Autogiro."

December 12th.—Lecture before the Bristol Branch, by Mr. W. S. Farren, M.B.E., M.A., F.R.Ae.S., on "Air Flow."

December 13th.—Lecture before the Yeovil Branch, by Mr. W. S. Farren, M.B.E., M.A., on "Air Flow."

December 14th.—Lecture before the Gloucester and Cheltenham Branch, by Flight Lieut. Kirk and Mr. Harper, on "Deck Landing," and Film with Running Commentary.

Students' Section

The following Lectures were read before the Students' Section during the year:—

January 10th.—" Some Notes on the High Pressure Pipe Effects on Fuel Injection," by C. W. Lawson, B.Sc. Chairman: Mr. H. R. Ricardo, F.R.S., F.R.Ae.S.

January 31st.—" Detonation," by F. R. B. King. Chairman: Mr. H. T. Tizard, F.R.S., F.R.Ae.S.

March 7th.—" Duralumin Applied to Aircraft Construction," by W. H. Lewis, B.Sc., A.C.G.I.

May 16th.—" Aircraft Instruments," by D. Hay Surgeoner. Chairman: Mr. H. E. Wimperis, C.B.E., F.R.Ae.S.

October 24th.—" Development of Air Transport," by Mr. E. V. Dolby. Chairman: Lieut.-Col. F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.

November 21st.—" The Use of Compressed Gas in Modern Commercial Aviation," by Mr. L. S. Campbell. Chairman: Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E.

In addition to the above lectures, visits were paid to the Fairey Aviation Company, at Hayes, on February 18th, the Royal Aircraft Establishment on the 6th May and 27th May, to Heston Airport on June 17th, and to the National Physical Laboratory on July 1st. These visits were great successes.

OFFICERS, 1933-1934.

Chairman: R. J. Schmidt, Ph.D.

Vice-Chairman: E. C. A. Backhaus.

Hon. Secretary: G. L. H. Bott.

Committee: J. P. Bertinat, F. G. R. Cook, J. Hanson, R. W. Hase, W. J. S. King-Smith, R. L. Lickley, G. H. Mansell, C. W. Prower.

Students' Representative

Mr. M. Langley was appointed by the Council to represent the Students' Section on the Council.

Lectures before Public Schools, etc.

January 5th.—Hull Aero Club. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

January 25th.—Manningtree School, Essex. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.

January 26th.—King's School, Chester. Flight Lieut. N. Comper, A.F.R.Ae.S.

January 30th.—Nottingham High School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 1st.—St. Andrew's Guild, Upper Norwood. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 3rd.—Royal Grammar School, High Wycombe. Major D. H. Kennedy, O.B.E., F.R.Ae.S.

February 3rd.—Upton College. Mr. J. T. Morton, A.F.R.Ae.S.

February 4th.—Rugby School. Lieut.-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.

February 4th.—Mill Hill School. Capt. A. G. Lamplugh, A.C.G.I., F.R.Ae.S., M.I.Ae.E.

February 4th.— Highgate School. W. O. Manning, Esq., F.R.Ae.S.

February 6th.—Birkenhead School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

February 7th.—Durham School. Dr. E. G. Richardson, D.Sc., Ph.D.

February 7th.—Blackpool Grammar School, Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.
February 10th.—Willaston School. Flight Lieut. N. Comper, A.F.R.Ae.S.
February 11th.—Reading School. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
February 17th.—St. Lawrence College, Ramsgate. Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I.
February 18th.—King's School, Worcester. F. Radcliffe, Esq., B.Sc., A.R.Ae.S.I.
February 18th.—Christ's Hospital. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
February 22nd.—Bristol Grammar School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.
February 23rd.—Denstone College. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
February 25th.—Charterhouse School. Mr. C. R. Fairey, M.B.E., F.R.Ae.S.
February 25th.—Eastbourne College. Mr. S. Scott Hall, M.Sc., D.I.C., A.F.R.Ae.S.
February 28th.—Liverpool College. Flight Lieut. N. Comper, A.F.R.Ae.S.
March 7th.—Haberdasher Aske's Hampstead School. Mr. J. H. Edge.
March 8th.—Bromsgrove School. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
March 8th.—Wrekin College. Major T. M. Barlow, M.Sc., F.R.Ae.S.
March 11th.—Ipswich Scientific Society. Mr. S. Scott Hall, M.Sc., D.I.C., A.F.R.Ae.S.
March 16th.—Liverpool University. Squadron Leader R. V. Goddard, R.A.F.
March 17th.—Epsom College. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.
March 22nd.—Liverpool Engineering Society. Flight Lieut. N. Comper, A.F.R.Ae.S.
April 13th.—Lincoln Technical College. Mr. J. T. Morton, A.F.R.Ae.S.
May 5th.—Kingswood Grammar School, Bristol. Flight Lieut. R. E. H. Allen, M.I.Ae.E., R.A.F.
October 11th.—North Durham County Secondary Schools. Dr. E. G. Richardson, B.A.
October 13th.—Haberdasher Aske's Hatcham Boys' School. Mr. M. L. Bramson, F.R.Ae.S.
October 14th.—Malvern College. Mr. F. Radcliffe, A.F.R.Ae.S.
October 14th.—Brighton College. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
October 16th.—Birkenhead School. Capt. J. Laurence Pritchard, Hon. F.R.Ae.S.
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October 19th.—Ryde School, I.O.W. Mr. T. A. S. Lloyd.
October 20th.—St. Albans School, Herts. Lieut. Cmdr. the Hon. J. M. Southwell, A.F.R.Ae.S.
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November 30th.—Peter Symonds School, Winchester. Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S.
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December 11th.—Newcastle-under-Lyme High School. Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.
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ABSTRACTS OF PATENT SPECIFICATIONS

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

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The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the library of the Society.

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Aeroplanes—Construction

399,190. *Improvements in and Relating to Brake Mechanism.* Avery, W. L., Blue House, Thorley, Bishop's Stortford, Hertfordshire. Date Jan. 27th, 1932. No. 2,470.

This specification relates to fluid-operated aircraft brake mechanisms of the type where differential braking for steering purposes is effected by a connection between the brake mechanism and the rudder bar of the aircraft, while normal braking is effected by a separate lever operated by the pilot.

The apparatus described consists of a mechanism containing pistons adopted to produce pressure in the brake mechanism. There is a rocking member attached to a lever, which rocking member may be actuated by a rudder bar connection to produce differential braking, while if the lever is actuated normal braking occurs. Arrangements are described for controlling the admission of fluid to the mechanism from the reservoir and for controlling the pressure developed.

399,332. *Safety Devices for Aeroplanes.* Voiciechauskis, B., Apskrities Mokesciu Inspekcija Siauliai, Lithuania. Nov. 9th, 1932, No. 31,700, and Nov. 29th, 1932, No. 33,809.

This specification refers to an arrangement by which the passenger in an aircraft is enclosed in a box which may be given the form of a cask-like cylinder. This box is so arranged that it may be thrown out of the aircraft from a moderate height and it is hoped that the passenger will not suffer from a severe shock at the fall of the box upon the ground. Various automatic devices are described for assisting the functioning of the arrangement and modifications are described for use in water craft.

399,453. *Improvements in or Relating to Aircraft Wings.* Dornier Metallbauten, G.M.B.H., and Dr. Eng. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), Sept. 9th, 1932. Dated (U.K.) June 21st, 1933. No. 17,719.

The device described here is intended to prevent what is described as the diversion or avulsion of the air flow when the aircraft is stalled, that is to say, when the auxiliary rear flaps are lowered to a considerable extent.

The arrangement proposed consists of an aerofoil fitted with a rear flap of the usual type. Fitted above and slightly in front of the hinge of the rear flap is an aerofoil-shaped member of narrow chord which extends along the wing in front of the rear flap. This member is arranged to pivot about its approximate centre of pressure. The rear flaps are to be movable in the same direction while the aerofoil-shaped members are to be movable in opposite directions in the manner of ailerons.

399,555. *Improvements in the Construction of Wings for Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. April 8th, 1932. No. 10,111.

This specification describes a wing construction in which the upper and lower booms of the ribs are constructed of members of uniform cross-section as, for instance, tubes. These tubes carry stringers which protrude beyond the ribs and which, in their turn, carry the fabric. Methods are given for constructing and attaching these stringers, which latter are shown as of a channel section provided with holes by means of which they can be threaded on to the rib booms. This method of construction is stated to be suitable also for the rudders, elevators, fuselages, etc., of aircraft.

399,622. *Brakes and Their Controls.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1, Goodyear, E. F., and Wright, J., of the Company's Works, Foleshill, Coventry, Warwickshire. July 2nd, 1932. No. 18,769.

The object of this invention is to diminish the loss of air in pneumatically-operated brake systems for aircraft by diminishing to the smallest possible extent the air space and piping by which the air escapes to atmosphere when the brakes are released. It is proposed to accomplish this by filling the piping and the distensible members within the brake drums with liquid acted on by the air pressure. Springs are attached to the brake shoes by which the liquid is forced out of the distensible member when the brake is released.

399,887. *Means for Mounting Members on Each Other about Intersecting Axes so as to Permit of their Independent Angular Adjustment.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Byfleet Road, Weybridge, Surrey. April 19th, 1932. No. 11,189.

This specification refers to a device which enables an elevator extending laterally of the tail end of a fuselage and carrying on the ends of such elevator the bearings for the posts of rudders.

The drawing shows a wire-braced tail with two elevator planes arranged as in a biplane. At each extremity of these planes a rudder is arranged. At the points where the spars of the elevators and the posts of the rudders come together there is fitted a special swivel pivot bearing allowing angular movement to either the rudders or elevators.

400,070. *Improvements in Aeroplane Undercarriages.* Dunlop, S., of H. D. Fitzpatrick and Co., 49 Chancery Lane, London, W.C.2. (Communicated by Fiat Società Anonima, 250 Via Nizza, Turin, Italy.) March 3rd, 1933. No. 6,518.

It is stated that an object of the invention is to provide an undercarriage consisting of elements which can be easily disassembled and which, in the case of braked wheels, allow of an equal distribution of the braking action on the frame members symmetrically arranged relatively to the middle plane of the wheel.

The undercarriage described has a forked vertical member and a forked member inclined backwards which is stabilised laterally by a lateral strut rigidly secured to the backwardly inclined member. When the wheel has a brake the disc carrying the brake shoes is so fitted that the braking action is equally distributed on the fork branches. The wheel is preferably fitted on the spindle by means of a sleeve engaging at its ends the branches of one of the forks.

400,338. *Improvements in the Framing of Boat, Pontoon, Aircraft and other Streamline Bodies.* Edward G. Budd Manufacturing Co., 2500, Hunting Park Avenue, Philadelphia, Pennsylvania, U.S.A. Convention date (U.S.A.) June 23rd, 1931.

This specification refers to the framing of streamline bodies and relates particularly to the relation of framework and sheathing of such bodies. A main object is to provide a construction which permits the standardisation of the transverse framing and the joining of the framework to the sheathing by, preferably, spot welding. A uniform section of transverse frame members is utilised, these members are framed with convex surfaces through which they may be readily joined to the sheathing, or to a frame member itself connected to the sheathing.

The drawings show frames constructed of members apparently semi-circular in section with a flat plate top, these members being connected either directly to the sheathing or to longitudinal members connected to the sheathing. These long structural members are channel in section and have saddles attached to them with semi-circular seats adopted to the frame members.

Airships

399,756. *Improvements in or Relating to Towing Arrangements for Aircraft.* Blochmann, E., 38, Ebert Allee, Dessau, Germany, and Pohlmann, 23a, Ringstrasse, Dessau, Germany. Convention date (Germany), May 24th, 1932.

It is proposed to combine the advantages of the aeroplane and airship by an arrangement by which one or more motorless airships carrying loads and passengers are towed by one or more aeroplanes. The airship may be provided with an auxiliary moving apparatus and a steering gear and the towing wire may be provided with a telephone cable.

Autogiros

399,446. *Improvements in and Relating to Rotary Blades or Wings for Aircraft.* G. and J. Weir, Ltd., and Bennett, J. A. J., both of Holm Foundry, Cathcart, Glasgow. May 24th, 1933. No. 14,966.

This invention refers to the method of construction of the rotary blades of autogiros and it is proposed to construct these blades by the use of a steel tube which is of the shape of the nose section of the aerofoil so that fairing is only necessary at the trailing edge of the blade to obtain the section desired. Pre-

viously these blades have been constructed with a circular steel tube carrying ribs of the aerofoil section desired. Advantages of cheapness, lightness and greater rigidity are claimed for the new construction. A claim is also made for a method of attaching the new type of blade to the root fitting.

399,693. *Improvements in Aircraft having Rotative Sustaining Means.* Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2. Convention date (U.S.A.), Feb. 12th, 1932.

The object of this invention is to improve the trim, stability and controllability of the autogiro aircraft and also the balance of the autogiro rotor. It is also claimed to reduce stresses and vibration. The rotor blades are arranged so that the axis of their articulations intersect the general rotational axis of the rotor and the independent swinging movements of the blades take place co-axially with the rotational axis.

The blades are attached each to a member which is independently mounted on the hub member permitting at least limited rotation. These intermediate blade-carrying members are axially spaced and the blades are attached thereto by forked blade root attachments. Some or all of these may be bent or joggled to make the rotor symmetrical. Auxiliary fixed wings are also referred to which are mounted so that they generate a rolling moment which opposes the variable rolling moment generated by the rotor.

Engines

399,238. *Improvements in or Relating to Prime Movers for Aircraft.* Aktiebolaget Milo, Kungsgatan 32, Stockholm, Sweden. Convention date (Germany), Nov. 23rd, 1931.

This is a gas turbine scheme in which the turbine itself may be of the multi-stage type, but the double rotating radial flow turbine is considered more suitable. The two sides of the turbine are arranged to drive compressors which collect air from an air intake extending centrally with regard to the axis of the plant, and arranged so that air is blown into it by the propeller. The whole plant is contained in a streamline casing and a reduction gear is provided for the propeller. Multiple turbines may be used if desired.

Helicopters

399,886. *Improvements in or Relating to Flying Machines of the Helicopter Type.* Porter, J. R., 6, Hurst Road, Twyford, Berkshire, England, and Fullalove, A. L., Market Place, Wantage, Berkshire, England. April 19th, 1932. No. 11,179.

The inventors propose to improve the lift of a lifting screw by surrounding it with a hollow ring whose inner diameter is the same as that of the screw. This hollow ring is attached to the engine mounting, which latter is attached to the fuselage by a pivotal bearing so that the screw and ring revolve in opposite directions when the engine is running, the engine driving the screw direct.

Variations of pressure are stated to be obtained on the ring when the plant is working which have the effect of causing an enhanced lift, and the device is also stated to act as a parachute. Several other advantages are claimed for the device.

Parachutes

400,385. *Improvements in Pack Parachutes.* Popelák, J., 68, Kralovská, Prague X, Czecho-Slovakia. Convention date (Czecho-Slovakia) August 17th, 1931.

In cases where the flaps of the parachute are connected in the closed position so that they engage studs fixed to one of the flaps, it is stated that the studs can assume such a position that they render difficult the release of the flaps. It is proposed to avoid this by the provision of studs having spherical bearings and by the provision of a pilot parachute frame made in the form of a book.

REVIEWS

The Romance of the Flying Mail

By Harry Harper and Robert Brenard. Published by George Routledge and Sons, Ltd. Price 10s. 6d.

It is probable that few authors have done more to interest the general public in aviation than Mr. Harry Harper. He induces them to forget, in their spare moments, the lure of the detective novel and, instead, to learn something about aeroplanes. He has a knack of serving up technical information in a most palatable form and, although the information he imparts does not go very deeply into the subject, it is doubtless as much as his reader can be expected to swallow, and it has the advantage of being correct.

In this work the two authors have traced the history of the air mail from the days when some attempt was made to send letters by balloon until to-day, when aircraft mail carrying is commonplace. They describe the early attempts to carry out postal services between England and the Continent with primitive equipment and inadequate weather information. The modern methods of wireless-ing information to pilots is dealt with and there are chapters dealing with the experiences of pilots and the developments in the aircraft used.

The whole book is of just the type to appeal to the non-technical reader, who, when he has finished it, will have obtained a good idea of the developments which have taken place in aerial postal services, and who will, it is hoped, think of the air mail on the next occasion when he has to send correspondence abroad.

As a Christmas gift to a member of the public the book could not be bettered. The giver can be assured that he will not only be giving pleasure to the recipient but will be encouraging interest in aviation.

Air Transport Manual

Published by Temple Press, Ltd. Price 3s. 6d.

This book aims at collecting the main facts and figures about air transport and arranging them so that they are easily available for reference. Details of all existing British air services are given, also complete lists of aerodromes, descriptions of British air transport aeroplanes and aero engines as supplied by the manufacturers. There are also articles on Air Ministry regulations and others on Maintenance, Cost of Operation, Wireless, Training of Personnel, Accessories, Fuels and Lubricants, etc., and the book concludes with a useful glossary of aeronautical terms.

Like most of the books of this type issued by the Temple Press there is little original matter included, and the work depends for its usefulness on its accuracy and on the convenient form in which the contents are arranged. With regard to accuracy, such developments as air brakes are not intended to assist aeroplanes in rising from the ground, as stated. The Rolls-Royce series of engines are credited with six cylinders instead of twelve, and it would be interesting to have particulars of the case where a compression ignition engine is stated to have improved the range of an aircraft by 54 per cent., which seems incredible.

The information given is well arranged and all those interested in air transport will find most of the information they require arranged in a way that facilitates reference, and there are also numerous illustrations. It is somewhat surprising that so little information is given on that most important subject aircraft instruments, though there is a list of the firms which manufacture them.

The Drama of Weather

By Sir Napier Shaw. Cambridge University Press. Price 7s. 6d.

There are few more important subjects to the inhabitants of these islands than that of weather. If you are a pilot of aircraft, knowledge of what may be expected is vital to your chance of reaching your destination; if a farmer, the whole of your yearly profits may depend on the period chosen for the gathering in of crops. Hence the weather wisdom with which the farmer has been credited in the past, and the attribution to the countryman of knowledge of many infallible signs of future weather, ranging from the height of the flight of swallows to the presence or absence of a dab of mud on a slug's tail.

During the last 100 years meteorology has attracted the attention of scientific men who have endeavoured to reduce the apparent chaos of the weather to some sort of system, by the application of which future weather events might be predicted. It was soon realised that little or nothing could be done without information about meteorological conditions from other parts of the globe, and that the greater the number of stations which transmitted such information, and the more quickly it was transmitted, the more accurate the forecast was likely to be. Hence any sort of weather prediction was practically impossible until the development of telegraphy, both wired and wireless, made rapid communication possible. Even to-day, the information is not complete, for there is practically no information available with regard to rainfall over the sea, a matter of great importance.

Sir Napier Shaw is known all over the world as an authority on this subject and he has traced for us the development of forecasting from early days to the present time, describing the instruments with which the meteorologist carries out his work, the diagrams and charts with which he expresses the results at which he has arrived, and in fact explains the whole system of modern weather forecasting in a way which it is easy for everyone to understand.

His collection of cloud photographs is excellent and his explanations of them clear, but one would have liked to have some photographic data, so that those who wish to take similar photographs would be saved from wasted plates. But the real importance of the book depends on the diagrams and letterpress of the later chapters, for it is in these chapters that the information about modern forecasting is contained. It is impossible to make full use of predictions, or understand a weather chart, without knowing the theory on which the first is made, or the latter constructed, and the author's pleasant English style and his keen sense of humour make the book easy to read.

The book is excellent value for 7s. 6d. and is thoroughly recommended as the best book on the subject for the user of forecasts, who will find herein all he wants to know.

Schneider Trophy

By Wing Commander A. H. Orlebar, A.F.C. Published by Seeley Service and Co., Ltd. Price 12s. 6d. net.

This book is a record of high achievement. It describes the work of the high speed flight and their preparations for the Schneider Trophy races of 1929 and 1931, culminating in the fly over for the Trophy in 1931 and the raising of the world's speed record to 407 miles an hour.

This work was led and inspired by the author of this book, who commanded the flight while it was in progress, and it is difficult to overestimate the credit due to him and to those serving under him for the successful completion of a difficult and dangerous job.

In accordance with Service tradition he endeavours to depreciate his own personal contribution, but the fact remains that it was the author himself who carried out the first tests on the newly-designed aircraft, found out their peculiarities and passed on the information to those who had to fly them subse-

quently. There is no doubt that it was due to his skill as a pilot and to the accuracy with which he analysed the behaviour of the various racing seaplanes that we were saved the large casualty list that was suffered by our friends the Italians. It is true that Lieut. R. L. Brinton was killed, because, in the author's words, " he thought that she had left (the water) at too steep an angle and, having let his stick go forward slightly, he had been caught by the instability." This slight movement of the stick stood between life and death. But it was Wing Commander Orlebar who had flown the machine for the first time, who had discovered the peculiarity of behaviour, and who had warned all his pilots against it; and the risk he took was obviously much greater than theirs. Brinton died through a slight error for which he cannot be blamed, " We know how easy is a slip at that one crucial point," and no man has given his life for the cause of aviation more gallantly than he.

But the author himself had at least one experience which few men would have survived. The machine he was flying developed wing flutter, which did not disappear until he came down to 50 feet above the water, at which height he was still doing a speed of 200 miles an hour. After landing it was found that the fuselage was buckled in front of the tail and that cracks had started to form in the plates. The trouble was cured without difficulty, but the description of the occurrence in Chapter X shows that the author has that instinct for doing the right thing in an emergency, which it is given to few men to possess.

Numerous minor troubles were met with during the tests, the machines were sometimes unexpectedly nose-heavy, petrol kept getting into the wrong float, radiators boiled and leaked, and a complete engine cylinder block had to be changed in the night before the race. This does not exhaust by any means the list of minor troubles, but it is interesting to note how quickly the nature of the trouble was grasped by the technical people and the short time it took for the appropriate remedy to be applied. It is clear that everyone, officers, Air Ministry officials and the technical representatives of the firms concerned must have worked together like a team.

Wing Commander Orlebar emphasises the disappointment of the flight when it was learnt that the 1931 race would have to be a fly over owing to the absence of the Italians. After describing one of the Italian machines which, unfortunately, could not be ready on time, and pointing out that it is likely to be superior to ours in speed owing to its two propellers mutually destroying each other's torque, he remarks: " It will be very interesting to compete against them." I seem to remember that a somewhat similar remark applied to slightly different conditions was made by one of the knights in Mallory's " Morte d'Arthur."

In dealing with the 1931 race the author does not forget the acknowledgments due to her who alone made it possible. I refer, of course, to Lady Houston. Let us hope that whenever there is a necessity for high achievement we shall have as gracious a Lady Bountiful to support it.

The question arises, is racing worth while? There is no doubt that in all fields of human endeavour the spirit of emulation produced by a competition has the effect of producing the best that is in the competitors. It is understood that Messrs. Rolls-Royce have estimated that the experimental work done in one year for the last Schneider Trophy race would have taken three years under normal conditions.

But the most important advantage is the improvement of the breed of aircraft. Normally aircraft design is governed by a variety of conditions of which speed is only one; fuselages, which must, for instance, contain passengers cannot be of the shape and size that would be required by purely aerodynamical considerations. But when we have, as in a racing machine, a concentration on one feature only with the designer's attention undissipated by other matters, then improvement in the speed of aircraft is bound to be rapid. Apart from engine power, the speed of an aeroplane depends on its shape, and when a better shape has

been discovered the improvement is available for all types. Features derived from lessons learnt in racing can be discovered on all modern aeroplanes.

The same improvement for the same reason is visible in the modern aero engine and the experience born of racing has brought nearer the day when aero engines weighing less than one pound per horse-power will be available for general use. Wing Commander Orlebar deserves the thanks of everyone, whether interested in aviation or not, for having written this book. As a record of adventure with an object in view of great importance, his work and the work of those who served under him deserve the utmost credit and it is well that it should be placed on record as an example of how a job of work should be done.

The Aeronautical Ground Engineer's "A" and "B" Licences

By Captain S. L. Collins. Published by John Hamilton, Ltd. Price 7s. 6d.

This book is said to have been specially prepared for the use of all those interested in aeronautical engineering, whether as engineers, students, or inspectors. It consists of a collection of loosely written and ill-arranged notes, which in their present form are of little use to anybody.

A few examples will suffice to indicate the style of this work. On page 11 he states, referring to in-line engines, that "the front bearers are usually allowed to be slightly raised above those of the rear."

Page 17, "All . . . rivets must be locked by riveting or split-pinning."

Page 28, "Adjustment of stops for limitation of movement of throttle and altitude levers on the carburettor must be checked. This is effected by a piece of thin paper being positioned between the appropriate stops and levers, in fully open and closed positions."

Page 51, "When gas starters are installed on the machine, the appropriate connections are made, and the functioning of the apparatus tested."

Page 70, referring to wire for oxy-acetylene welding, "A suitable welding wire composition consists of manganese, carbon, sulphur phosphorus."

The book is not recommended.

Estimating for Mechanical Engineers

By L. E. Bunnett, A.M.I.P.E. Published by Sir Isaac Pitman and Sons, Ltd. Price 10s. 6d.

This book deals with the costing and estimating side of manufacturing engineering goods, and Mr. Bunnett, who obviously knows his subject thoroughly, has dealt with his matter in a very practical way.

He commences by defining his terms, and rightly points out that there is much hazy thought about what costs are actually comprehended under such a term as establishment charges. He deals with mensuration, methods of remunerating labour, various types of labour from the pattern shop to the final inspection, and adds many useful notes on estimating in cases where the estimate can be little more than guesswork. His illustrations are excellent and the large number of examples of machined parts with production times add much to the value of the work.

He is dealing primarily with general engineering, so his references to aircraft work are few, but it is interesting to note a reference to the speed of riveting which has been attained by Messrs. Fairey. His estimate of an additional 10 per cent. as a cost allowance for Government inspection would be hardly sufficient in an aircraft factory, but in fairness to the author it should be said that he realises that this estimate may be very wide of the mark in special instances.

He describes the various piecework systems in common use, such as straight piecework, the premium bonus system and the Rowan system, and notes the

popularity of straight piecework in this country. One reason for this, that he does not mention, is that such a system is easily understood by the men. A man whose wages are calculated by a method he does not understand is always inclined to think that he has been underpaid.

The suggestion that the costs of tools to be produced in the firm's own toolroom may be estimated by obtaining a price from another firm experienced in such work hardly seems fair to the other firm, but tool estimates are usually the most difficult part of estimating, especially when such matters as the breakage of small taps is concerned.

It should be noted that it does not always pay to use the smallest diameter of bar for a given job. In heat treated bar there is sometimes a hard skin, and it saves time and tools if the cut is made deeper than would be necessary if the skin were not there.

This book will appeal to everyone interested in production and can be thoroughly recommended.

Adventure Above the Clouds

By F. V. Monk and H. T. Winter. Published by Blackie and Sons, Ltd. Price 3s. 6d.

This book deals mainly with the history of ballooning, starting with the early ascents of Montgolfier and Charles and finishing with the recent adventures of Professor Piccard. There is also a chapter dealing with Captain Uwins' aeroplane height record, and the work concludes with a description of the recent experiments with rocket propulsion.

There is matter here for a most interesting book. It is good that the adventures of the early balloonists should be written once more for the information of the younger generation, for the courage and resource of these men has not been surpassed by any of their successors, the aeroplane pilots. But the author who has dealt with this part of the book uses a style of writing which may effectively stimulate the jaded literary appetite of a reader nurtured on " best sellers," but which fails to produce the desired effect on the ordinary reader owing to its gross over emphasis. When a balloon burst in the air, the torn envelope " was fluttering and dancing a dance of death over the doomed ones." On the next page one learns that the occupants survived. Winds do not blow gales, they " screech through the tossing leaves " and the remains of a tattered balloon are not blown away, they " flee on the relentless blast." This author believes that the height of a balloon can be obtained from a thermometer (page 78) and states that $-27°$F. is $11°$ of frost, whereas it is actually $59°$.

The other author is much more readable, his descriptions of wet and dry thermometers, dew points, and other scientific matters are well done, and if his remarks on scientific matters would not always pass the scrutiny of a modern physicist, they are sufficiently accurate for a work of this type.

The book would make an acceptable Christmas present for boys.

By Air

Sir Harry Britain, K.B.E., C.M.G., LL.D. Published by Hutchinson and Co. Price 12s. 6d.

Sir Harry Britain has had a long experience with air matters. He started by going up with the late C. S. Rolls in a balloon in 1906, was one of the first Englishmen to see Wilbur Wright fly at Le Mans in 1908, and has followed the progress of aviation closely ever since, and has flown as a passenger in most countries in the world.

He gives an interesting account of the early days of Imperial Airways, describes the adventures of those who first blazed the trail of the main Empire air routes, deals with air photography, international barriers, the Royal Air Force,

etc., and the result is a very readable book which should make a special appeal to those who still know little about air matters. Books of this type, though including little or nothing which is not known to those who are actually engaged in aviation, are of great value as propaganda, as they are read by many who would never look at a more technical work.

His best chapter is that dealing with the Royal Air Force, and this should be published separately and circulated to all those who still seem to believe that the principal work of the R.A.F. consists in bombing inoffensive natives, and who do not appreciate the immense saving in life and money which has resulted from the use of the Air Arm in frontier warfare.

There are one or two errors. Prof. Piccard made his ascent in a sphere constructed of aluminium alloy, not of steel. It was certainly not illegal to fly in 1909, as the author states, whatever was the charge against Mr. A. V. Roe in that year, and Commandante Ramon Franes in 1926 was not the first man to fly from Europe to South America. This feat was actually accomplished by a Portuguese, Commander Saccadura Cabral, on a Rolls-Royce Fairey seaplane in the year 1922, who succeeded in getting safely across, though he broke two machines on the journey.

The book should be read by all those, and there are many, who still do not know what aviation can do. It is difficult to imagine anyone not wanting to fly over the main Empire Air Routes after reading the author's description of the comfort, security and speed with which such flights are made.

CORRESPONDENCE

To the Editor of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Canadian Building, Slater Street, Ottawa,

November 16th, 1933.

Dear Captain Pritchard,—In the discussion on Mr. Garner's paper on research, an account of which was published in the October number of the Journal, Mr. Corvin Kroukovsky made certain statements which might lead people to suppose that the Department of National Defence in Canada made some comparative tests in order to determine the difference between floats having a 20° dead rise and a 30° dead rise. Actually the Department made no such tests. What did occur was that the Department made acceptance tests on a particular type of seaplane which was fitted with Edo floats which happened to have a 20° dead rise. Later on, an airframe and engine of the same type was tested on another Edo float having entirely different lines, and having, incidentally, greater buoyancy than the first floats. The second set of floats which happened to have a 30° dead rise actually gave a better performance than the first set. It is not considered that Mr. Kroukovsky has any justification for drawing the conclusions inferred by his contribution to the discussion.

Yours truly,

A. FERRIER, Squadron Leader,

Secretary, Aeronautical Section, Ottawa Branch, E.I.C.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JANUARY, 1933

1933

The President and Council wish all members a prosperous New Year.

They wish to thank all members for their help during 1932, a year of great difficulty. Despite that the Society is steadily growing in strength and the Council are well aware that this is largely due to the attitude of the members themselves. Without their ready co-operation the Society would not be in the progressive state it now is.

Journal

Certain changes are being made this year in the make-up of the JOURNAL. The advertisements on the front page of the cover are being dropped as contracts are filled, and the whole of the front page will be devoted to the JOURNAL and its contents. The title headings at the beginning of each monthly issue will be dropped so that the JOURNAL, when it is bound, will conform with the annual proceedings of other societies and institutions. The advertisement pages are being printed on special art paper. These do not, of course, appear in the bound volume.

Informal Debate

On Monday, January 16th, 1933, the Royal Aeronautical Society is to experiment with a new idea. On that date an informal debate will be held at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, in order that many aspects of civil aviation may be discussed more freely and over a wider range than is possible in a more formal set lecture where the subject is more limited.

The origin of the debate lies in the great interest shown in the recent lecture by Mr. H. G. Travers on "Civil Primary Training," and the demand for a further discussion on the subject. A number of prominent designers, pilots and others have promised to be present and to take part in the debate. The following motion will be proposed:—

> "Civil Aviation differs from Military Aviation and should be treated accordingly."

The motion is drawn in wide terms so that the following controversial points raised in Mr. Travers' lecture may be debated:—

(1) The control and regulation of civil aircraft—national and international.
(2) The design of civil aircraft from a national and international (disarmament) point of view.
(3) The training of civilian pilots.
(4) The costs of civil aviation.

It is hoped that all those interested in the future of civil aviation will attend the debate so that as representative a discussion as possible may take place.

The chair will be taken at 6.30 p.m. by the President of the Society, Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Council Meeting

A meeting of the Council was held on Tuesday, December 13th, 1932, in the offices of the Society.

Present: Mr. C. R. Fairey, President, in the chair; Mr. Griffith Brewer, Major G. P. Bulman, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. J. E. Hodgson (Hon. Librarian), Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Mr. W. O. Manning, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, Mr. A. F. Sidgreaves (Vice-President), Professor R. V. Southwell, Mr. L. A. Wingfield (Hon. Solicitor).

Among the business considered was the following:—The Report of the Finance Committee; the Report of the Grading Committee; the Air League; the Lecture Programme for the Second Half of the Session.

Elections

At a meeting of the Council held on 13th December, 1932, the following were elected:—

Fellow.—Frederick Charles Johansen.

Associate Fellow.—John Eustace Arthur Baldwin, George Francis Meager, George Panagiotis Tzannetakis.

Associate.—Biraja Madhab Gupta, Richard Humble, Clive Edmund Gordon Murray Waller (Australian Branch).

Student.—Montague Waddel Harvey, Frederick Charles Hentsch, Alan King Martin (Australian Branch), Frederick Norman Montague, Sven Christian Poulsen.

Companion.—William Garrow-Fisher (from Student), Herbert Gooding, Clement James Selden (from Student).

Luncheon to Mrs. J. A. Mollison

A luncheon was given to Mrs. J. A. Mollison at the Park Lane Hotel, on Monday, December 19th, by the Royal Aeronautical Society, the Royal Aero Club and the Society of British Aircraft Constructors, in honour of her double record flight from London to Cape Town and back.

The President of the Society, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was in the chair, supported by Lord Gorell, Chairman of the Royal Aero Club, and Mr. Handley Page, representing the Society of British Aircraft Constructors.

Among those who attended the luncheon were the following:—

Lieutenant de Vaisseau Albertas (French Air Attaché); Flight Lieut. J. B. Allen, R.A.F.O.

Major T. M. Barlow, M.Sc., F.R.Ae.S.; Capt. R. R. Bentley; F. G. L. Bertram, Esq., C.B.E., M.A. (Deputy Director of Civil Aviation); Griffith Brewer, Esq., F.R.Ae.S.; Lieut.-Col. W. A. Bristow, M.I.E.E., M.I.A.E., F.R.Ae.S.; J. S. Buchanan, Esq., O.B.E., F.R.Ae.S. (Deputy Director of Technical Development); Major G. P. Bulman, O.B.E., F.R.Ae.S.; Flight Lieut. P. W. S. Bulman, M.C., A.F.C., A.F.R.Ae.S.; Major H. G. Brackley, D.S.O., D.S.C.; Air Marshal Sir H. R. M. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C.; E. C. Bowyer, Esq. (the Society of British Aircraft Constructors).

Major Corin; F. S. Cotton, Esq.; William Courtenay, Esq.

Capt. G. DeHavilland, O.B.E., A.F.C., F.R.Ae.S.; Flight Lieut. G. G. H. DuBoulay.

E. C. Gordon England, Esq., F.R.Ae.S. (Chairman, British Gliding Association); Capt. F. Entwistle, B.Sc.

A. H. R. Fedden, Esq., F.R.Ae.S.; Captain E. T. della Floresta, D.Sc. (Italian Air Attaché); Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E., F.R.Ae.S.

H. R. Gillman, Esq., A.F.R.Ae.S. (Secretary, the Society of British Aircraft Constructors); Lord Gorell, C.B.E., O.B.E., M.C., M.A. (Chairman of the Royal Aero Club); A. Gouge, Esq., F.R.Ae.S.; C. G. Grey, Esq. (Editor, *The Aeroplane*); Capt. the Hon. F. E. Guest, C.B.E., D.S.O., M.P.

Major F. B. Halford, F.R.Ae.S.; Squadron Leader H. L. J. Hinkler, A.F.C.; Captain W. L. Hope; Commander Norman D. Holbrook, V.C.

A. C. M. Jackaman, Esq., A.M.I.Ae.E.

Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Capt. A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E.; Air Vice-Marshal A. M. Longmore, C.B., D.S.O.; A. Limb, Esq.

Sir Francis K. McClean, A.F.C., A.F.R.Ae.S.; Capt. Norman Macmillan, M.C., A.F.C., A.F.R.Ae.S.; J. Stewart Mallam, Esq., F.C.A.; Major R. H. Mayo, O.B.E., F.R.Ae.S.; L. V. Meadowcroft, Esq.; J. A. Mollison, Esq.; Commander G. D. Murray, U.S.N. (American Air Attaché, Naval).

Colonel H. Nerinx (Belgian Military Attaché).

Colonel M. O'Gorman, C.B., D.Sc., F.R.Ae.S.

F. Handley Page, Esq., C.B.E., F.R.Ae.S.; H. E. Perrin, Esq. (Secretary, Royal Aero Club); The Press Association; Capt. J. Laurence Pritchard, Hon.F.R.Ae.S. (Secretary, Royal Aeronautical Society); Capt. W. G. Pudney.

C. H. Roberts, Esq. (College of Aeronautical Engineering).

Air Chief Marshal Sir John M. Salmond, G.C.B., C.M.G., C.V.O., D.S.O., LL.D. (Chief of the Air Staff); Major M. F. Scanlon, D.S.M. (American Air Attaché, Military); Herr A. H. Van Scherpenberg (Secretary of the German Embassy); the Master of Sempill, A.F.C., F.R.Ae.S. (Immediate Past-President, Royal Aeronautical Society); Lieut.-Col F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S. (Director of Civil Aviation); G. C. Shepherd, Esq. (*The Times*); H. O. Short, Esq., F.R.Ae.S.; A. F. Sidgreaves, Esq., O.B.E. (Vice-President, Royal Aeronautical Society); G. C. Simpson, Esq., C.B., F.R.S., D.Sc., Hon.LL.D. (Director of the Meteorological Office); Stanley Spooner, Esq. (Editor, *Flight*); C. Stanhope Sprigg, Esq. (Editor, *Air and Airways*); Major Oliver Stewart (*The Morning Post*); B. Stevenson, Esq. (House Secretary, Royal Aero Club).

Major H. G. Travers, D.S.C.; Major C. C. Turner, A.F.R.Ae.S. (*The Daily Telegraph*); Dr. A. P. Thurston, F.R.Ae.S.

Capt. C. F. Uwins.

Sir A. Verdon-Roe, O.B.E., F.R.Ae.S.; Air Vice-Marshal Sir Vyell Vyvyan, K.C.B., D.S.O.; H. T. Vane, Esq., C.B.E.

Lord Wakefield of Hythe, C.B.E., Hon.LL.D., Hon.F.R.Ae.S.; C. C. Walker, Esq., F.R.Ae.S.; R. P. Wilson, Esq., C.B.E.; H. E. Wimperis, Esq., C.B.E., F.R.Ae.S. (Director of Scientific Research); Lawrence A. Wingfield, Esq., M.C., D.F.C. (Clerk to the Guild of Air Pilots and Air Navigators); J. L. R. Waplington, Esq. (Secretary, British Gliding Association); Squadron Leader Maurice Wright, A.F.C., A.F.R.Ae.S.

Subscriptions

Members are reminded that their subscriptions are due on January 1st, 1933. The Society, like all other institutions, is passing through a difficult time, and

the Council hope that every member will make every effort to pay his subscription as early as possible in the new year. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	3	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

* £1 1s. 0d. without Journal.

Acknowledgments

The Council gratefully acknowledge the following:—From the Society of British Aircraft Constructors, a number of very useful books and papers; from Mr. T. B. Ringwood, several back numbers of the Journal; from Professor Ph. Theodorides and Professor A. F. Zahm, technical papers by them; from Flight Lieut. R. E. H. Allen, slides of the Autogiro controlling the traffic on Derby Day, 1932 (piloted by Flight Lieut. Allen); from Mr. Tilghman Richards, slides of 1913-1914 types of annular aeroplane (Cedric-Lee).

Forthcoming Events

Thursday, January 5th.—Lecture before the Hull Aero Club by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, January 12th.—Lecture, "Airship Development Abroad," by Squadron Leader R. S. Booth, A.F.C., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Monday, January 16th.—Informal debate at the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, January 19th.—Lecture before the Yeovil Branch by Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S., on "American Aviation Progress."

Wednesday, January 25th.—Lecture before Manningtree School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, January 26th.—Lecture on "Human Limits in Flying," by Wing Commander G. S. Marshall, O.B.E., M.R.C.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2.

Thursday, January 26th.—Lecture before King's School, Chester, by Flight Lieut. N. Comper, A.F.R.Ae.S.

Monday, January 30th.—Lecture before Nottingham High School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

J. Laurence Pritchard, *Secretary*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

FEBRUARY, 1933

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they shall be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Under Rule 105 the Annual General Meeting is held at some convenient date before the end of March of each year, so that nominations must be received during the first week in March.

Council Meeting

A meeting of Council was held on Tuesday, January 17th, 1933, in the Offices of the Society.

Present: Professor L. Bairstow (Vice-President) in the chair; Mr. R. Blackburn, Mr. Griffith Brewer, Sir R. Brooke-Popham (Vice-President), Major G. P. Bulman, Mr. R. S. Capon, Mr. Gordon England, Mr. A. H. Hall, Mr. M. Langley, Mr. W. O. Manning, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. E. F. Relf, Mr. H. E. Wimperis (Vice-President), Mr. Lawrence Wingfield, Mr. McKinnon Wood.

Among the business transacted was the following:—The Report of the Finance Committee; the Report of the Grading Committee; the Wilbur Wright Memorial Lecture for 1933; suggestions for the award of the Segrave Trophy; the appointment of a representative on the Council of the British Gliding Association.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 17th January, 1933:—

Fellows.—Herbert Alfred Mettam (from A.F.), Herbert Charles Henry Townend (from A.F.).

Associate Fellows.—James Valentine Connolly (from A., Australasian Branch), Wallace Charles Devereux.

Associate Member.—Reginald David Easton.

Associates.—The Marquis Hachisuka, Lee Cameron Lathrop Murray.

Students.—John William Thomas Brackett, Albert Dawson, Jack Hanson, Anthony Major Henniker, William James Stuart King-Smith, Dennis A. Letts, Jack Lobley, Ian Frank Meathrel, Darabshah P. Pavri, Hugh Guyer Small, Talbot Cecil Cochran Sweet-Escott, Kenneth Edmund Westover.

Companions.—William Lindsay Everard, Bernard William Galpin.

British Gliding Association

At the Council Meeting held on Tuesday, January 17th, 1933, Mr. W. O. Manning was appointed the Society's representative on the Council of the British Gliding Association.

Subscriptions

Members are reminded that their subscriptions were due on January 1st, 1933. The Society, like all other institutions, is passing through a difficult time, and the Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

	Home.			Abroad.		
	£	s.	d.	£	s.	d.
Fellow	4	4	0	3	3	0
Member	4	4	0	3	3	0
Associate Fellow	3	3	0	2	2	0
Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

* £1 1s. 0d. without Journal.

Acknowledgment

The Council gratefully acknowledge a set of back numbers of the Journal from Mr. F. P. Walsh.

Forthcoming Events

Wednesday, February 1st.—Lecture before St. Andrew's Guild, Upper Norwood, by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, February 2nd.—Lecture, "The Operation of Aircraft Over Tropical Routes," by Mr. A. Plesman, Director of the Royal Dutch Air Lines, Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Friday, February 3rd.—Lecture before Royal Grammar School, High Wycombe, by Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Friday, February 3rd.—Lecture before Upton College by Mr. J. T. Morton, A.F.R.Ae.S.

Saturday, February 4th.—Lecture before Rugby School by Lieut.-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.

Saturday, February 4th.—Lecture before Mill Hill School by Capt. A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E.

Saturday, February 4th.—Lecture before Highgate School by Mr. W. O. Manning, F.R.Ae.S.

Monday, February 6th.—Lecture before Birkenhead School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Tuesday, February 7th.—Lecture before Durham School by E. G. Richardson, Esq., D.Sc., Ph.D.

Tuesday, February 7th.—Lecture before Blackpool High School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Friday, February 10th.—Lecture before Willaston School by Flight Lieut. N. Comper, A.F.R.Ae.S.

Saturday, February 11th.—Lecture before Reading School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, February 16th.—Lecture, "Cloud Formation with Reference to Up and Down Currents for Gliding," by Sir Gilbert T. Walker, C.S.I., F.R.A.S., F.R.S.

Thursday, February 16th.—Lecture before the Yeovil Branch by Major G. P. Bulman, O.B.E., F.R.Ae.S., on "Aero Engine Development."

Friday, February 17th.—Lecture before St. Lawrence College, Ramsgate, by Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I.

Saturday, February 18th.—Lecture before King's School, Worcester, by Mr. F. Radcliffe, B.Sc., A.R.Ae.S.I.

Saturday, February 18th.—Lecture before Christ's Hospital School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Wednesday, February 22nd.—Lecture before Bristol Grammar School by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, February 23rd.—Lecture before Denstone College by Capt. J. Laurence Pritchard, Hon.F.R.Ae.S.

Friday, February 24th.—Lecture before the Gloster and Cheltenham Branch by Capt. C. H. Latimer Needham, M.Sc., F.R.Ae.S., on "The Conquest of Soaring Flight."

Saturday, February 25th.—Lecture before Charterhouse School by Mr. C. R. Fairey, M.B.E., F.R.Ae.S. (President).

Saturday, February 25th.—Lecture before Eastbourne College by Mr. S. Scott-Hall, M.Sc., D.I.C., A.F.R.Ae.S.

Tuesday, February 28th.—Lecture before Liverpool College by Flight Lieut. N. Comper, A.F.R.Ae.S.

J. LAURENCE PRITCHARD, *Secretary*

OBITUARY

LAURENCE CHASE SHARMAN.

The Council greatly regret to record the death of Commander Laurence Chase Sharman, R.N., a Companion of the Society. Commander Sharman was one of the youngest officers attached to the Fleet Air Arm and had every prospect of a brilliant career. He entered the Navy in 1912 and served with distinction in the Navy in 1914-18. He was attached to the Fleet Air Arm in 1925 and served on the "Furious" and "Courageous" until he was transferred to the Admiralty in 1931.

Commander Sharman spoke at a number of lectures of the Society and showed a thorough grasp of the problems connected with naval flying. A man of great personal charm, his loss will be deeply felt by all those who had the privilege of knowing him.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

MARCH, 1933

Election of Council

Attention is drawn to Rules 68-85 regulating the constitution of the Council and in particular to Rules 79 and 81, which read as follows:—

RULE 79.—One half of the Council (excluding the President and the Immediate Past-President if a member of Council) shall retire annually. The members who shall retire shall be those longest in office, except as provided in Rule 85. Retiring members of Council who have served two terms in succession (four years) shall not be eligible for re-election until the next annual election, when they shall be eligible.

RULE 81.—Nominations of candidates for election to the Council must be received by the Secretary not less than twenty-one days before the Annual General Meeting, with an intimation in writing by the candidates that they are willing to serve. Nominations must be signed by one supporter and two seconders, who must each be entitled to vote in the R.Ae.S.I.

Nominations of candidates for election to the Council must be received by the Secretary on or before Tuesday, March 7th, 1933.

Annual General Meeting

The Annual General Meeting of the Society will be held in the Offices of the Society, 7, Albemarle Street, W.1, at 6.30 p.m., on Tuesday, March 28th, 1933.

Council Meeting

A meeting of the Council was held in the Offices of the Society on Tuesday, February 14th, 1933.

Present: In the Chair, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President; Professor L. Bairstow (Vice-President), Major T. M. Barlow, Mr. Griffith Brewer, Sir R. Brooke-Popham (Vice-President), Mr. W. S. Farren, Mr. A. H. Hall, Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Mr. W. O. Manning, Mr. R. K. Pierson, The Master of Sempill (Past-President), Professor R. V. Southwell, Mr. H. E. Wimperis (Vice-President).

Among the business considered was the following:—The award of the Gold Medal of the Society to Sir Richard Glazebrook, K.C.B., F.R.S., F.R.Ae.S.; the Report of the Finance Committee; the Report of the Grading Committee; the Audited Accounts of Aerial Science, Ltd., and Aeronautical Trusts, Ltd.; the Report of the Council for the Year 1932; the Annual General Meeting; consideration of New Awards of the Society.

Gold Medal

At a meeting of the Council held on Tuesday, February 14th, 1933, the Gold Medal of the Society was unanimously awarded to Sir Richard Glazebrook, K.C.B., F.R.S., F.R.Ae.S., Chairman of the Aeronautical Research Committee.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 14th February, 1933:—

Associate Fellows.—Henry Herbert Gardner, Francis Olaf Thornton, Kenneth Franklin Tupper (from Companion).

Associate Members.—Ralph Alexander, William James Spencer Edmunds.

Associates.—John Vivian Holman, Cyril Arundel Penberthy (from Student).

Student.—Gerald Lawson Hulton Bott.

Examinations

Examinations for Associate Fellowship and Associate Membership were held in the Offices of the Society on December 30th and 31st. The following have satisfied the examiners in their respective subjects:—

ASSOCIATE FELLOWSHIP EXAMINATION.

Strength and Elasticity of Materials and Theory of Structures.—H. O. Baker, J. G. Brown, F. S. Dorabjee, J. Elston, R. R. Goodbody, K. C. Griggs, K. Hitchins, J. C. Hornby, C. H. Hunter, T. H. Jackson, J. A. Kelly, A. H. Martin, B. C. Puri, E. J. Riddle, E. H. Welch (First Place), W. Wilson.

Heat Engines.—J. G. Brown, J. Elston, S. C. Fairbairn, A. G. Gooch, R. R. Goodbody, K. C. Griggs, J. C. Hornby, W. A. K. Igoe, C. G. C. Leonard, W. P. Lewis, G. A. Mann, A. M. Martin, R. N. Mirza (First Place), B. C. Puri, E. J. Riddle, F. D. Sawyer, D. Stewart, P. N. Vincent, E. H. Welch, R. N. Wimshurst.

Chemistry and Metallurgy.—S. C. Fairbairn, A. G. Gooch (First Place), K. Hitchins, W. A. K. Igoe, T. H. Jackson, H. M. Kemp, R. E. Leete, R. N. Mirza, F. D. Sawyer, D. Stewart, R. N. Wimshurst.

Aerodynamics.—H. O. Baker, A. Davis, F. S. Kramer, R. E. Leete, J. van Hattum (First Place), W. Wilson.

Mathematics.—S. Shirodker.

Meteorology and Navigation.—F. S. Kramer.

ASSOCIATE MEMBERSHIP EXAMINATION.

Design of Aircraft.—C. G. Rogers, J. K. Wheatley (First Place), H. B. Wilkinson.

Air Transport.—G. R. Irvine, H. B. Wilkinson (First Place).

Heat Engines.—R. N. Kathju, A. R. Osborn, H. W. R. A. Miller (First Place).

Chemistry and Metallurgy.—R N. Kathju (First Place), H. W. R. A. Miller.

Strength and Elasticity of Materials and Theory of Structures.—C. G. Rogers, J. K. Wheatley (First Place).

Forty-four candidates sat for the examinations—43 at the Offices of the Society and one under supervision (arranged by Professor A. Klemin) at the New York University. Of the 44 candidates, 27 passed in both subjects taken, 14 failed in one subject, and three failed in both subjects.

The examination papers were set and marked under the supervision of Professor F. T. Hill, of the Imperial College. The papers have been reprinted, and, together with 24 previous papers, may be obtained from the Office, price 1s., or 1s. 3d. post free.

The following is an extract from the Examiner's report: " One is left with the impression that a good many of the candidates taking Associate Fellowship have received a technical rather than a scientific training, and would have done themselves more credit to the Associate Membership papers."

Subscriptions

Members are reminded that their subscriptions were due on January 1st, 1933. The Society, like all other institutions, is passing through a difficult time, and the Council hope that every member will make every effort to pay his subscription as early as possible. The rates are:—

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Associate Member	3	3	0	2	2	0
Associate	*2	2	0	*2	2	0
Student	1	1	0	1	1	0
Companion	2	2	0	2	2	0
Founder Member	2	2	0	2	2	0

* £1 1s. 0d. without Journal.

Forthcoming Events

Thursday, March 2nd.—Lecture before the Yeovil Branch. " Aircraft Armament Installations," by Squadron Leader C. Crawford, R.A.F.

Tuesday, March 7th.—" Some Notes and Observations on Petrol and Diesel Engines," by Mr. H. R. Ricardo, B.A., F.R.S., F.R.Ae.S. (Joint Meeting with the Institution of Automobile Engineers. Royal Geographical Society, 7.30 p.m.).

Tuesday, March 7th.—Lecture before Haberdasher Aske's Hampstead School by J. H. Edge, Esq., Comp. R.Ae.S.I.

Wednesday, March 8th.—Lecture before Wrekin College by Major T. M. Barlow, M.Sc., F.R.Ae.S.

Wednesday, March 8th.—Lecture before Bromsgrove School by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Thursday, March 9th.—Lecture by R. McKinnon Wood, Esq., O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S., on " Engine Cooling Research," before the Society in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Saturday, March 11th.—Lecture before the Ipswich Scientific Society by S. Scott Hall, Esq., M.Sc., D.I.C., A.F.R.Ae.S.

Thursday, March 16th.—Lecture by Professor A. Toupoleff on " The Work of the Central Aerodynamic Institute, Moscow," before the Society, in the Lecture Theatre of the Institute of Civil Engineers, Great George Street, Westminster, S.W.1., at 6.30 p.m.

Thursday, March 16th.—Lecture before the Yeovil Branch by Mr. Sammons on " Petter Oil Engines."

Thursday, March 16th.—Lecture before Liverpool University by Squadron Leader R. V. Goddard, R.A.F.

Friday, March 17th.—Lecture before Epsom College by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Saturday, March 18th.—Visit by the Students' Section to the Works of Messrs. Short Brothers, Rochester.

Wednesday, March 22nd.—Lecture before the Liverpool Engineering Society by Flight-Lieutenant N. Comper, A.F.R.Ae.S.

Tuesday, March 28th.—ANNUAL GENERAL MEETING of the Society at 6.30 p.m. in the Offices of the Society.

Wednesday, March 29th.—Lecture before the Yeovil Branch by W. S. Farren, Esq., M.B.E., F.R.Ae.S., on "Air Flow."

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

APRIL, 1933

Wilbur Wright Memorial Lecture

The 21st Wilbur Wright Memorial Lecture will be delivered by Colonel F. P. Lahm, Air Corps, U.S. Army, on May 30th, 1933, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi. The lecture will be entitled "Training the Airplane Pilot." It will be preceded by the Annual Council Dinner.

Council, 1933-34

There were ten vacancies for the Council in March, and ten nominations, so that no election was necessary. The following is the Council for 1933-34. Newly elected members are marked with an asterisk:—

President:

Mr. C. R. Fairey, M.B.E., F.R.Ae.S.

Past-President:

Colonel the Master of Sempill, A.F.C., F.R.Ae.S.

Vice-Presidents:

Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S.
Air Marshal Sir H. R. M. Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C., F.R.Ae.S.

Council:

*Captain P. D. Acland.
*Major J. S. Buchanan, O.B.E., A.M.I.Mech.E., F.R.Ae.S.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S.
Mr. R. S. Capon, O.B.E., B.A., F.R.Ae.S.
Mr. E. C. Gordon England, F.R.Ae.S.
Mr. W. S. Farren, M.B.E., F.R.Ae.S., M.I.Ae.E.
*Mr. A. H. Hall, C.B.E., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
*Captain A. G. Lamplugh, F.R.G.S., F.R.Ae.S.
*Mr. M. Langley, A.M.I.Ae.E., A.M.Inst.N.A.
*Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. R. K. Pierson, M.B.E., B.Sc., Assoc.M.Inst.C.E., F.R.Ae.S.
Mr. D. R. Pye, M.A., F.R.Ae.S.
Mr. E. F. Relf, A.R.C.S., F.R.Ae.S.
*Lieut.-Col. F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S.
*Sir J. D. Siddeley, C.B.E., F.R.Ae.S.
*Mr. F. Sigrist, M.B.E., F.R.Ae.S.
*Mr. O. E. Simmonds, M.A., F.R.Ae.S., M.P.
Professor R. V. Southwell, M.A., F.R.S., F.R.Ae.S.

Hon. Treasurer:
Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Hon. Solicitor:
Mr. Lawrence A. Wingfield, M.C., D.F.C., A.R.Ae.S.I.

Hon. Librarian:
Mr. J. E. Hodgson.

Hon. Accountant:
Mr. A. N. D. Smith, F.C.A.

Council Meeting

A Meeting of Council was held on Tuesday, March 14th, 1933, in the offices of the Society.

Present: Mr. C. R. Fairey (President). Professor L. Bairstow (Vice-President), Major G. P. Bulman, Mr. R. S. Capon, Mr. A. H. Hall, Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Mr. W. O. Manning, the Master of Sempill (Past-President), Mr. Lawrence Wingfield (Hon. Solicitor).

Among the business transacted was the following:—The Report of the Finance Committee; the Report of the Grading Committee; the Report of the Ground Engineers' Committee; the appointment of a representative of the Students' Section on the Council.

Students' Representative

Mr. M. Langley was appointed by the Council to represent the Students' Section on the Council.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 14th March, 1933:—

Fellow.—John Frederick Andrews Higgins.

Associate Fellows.—Reginald Sydney Brown, Fred S. Kramer, Reginald Herbert Schlotel, Theodore Michael Walker (from Student).

Associate Members.—Athol Rudolph Mayhill (from Companion), Henry William Rix Allen Miller.

Students.—Michel Alexander Benachi, Kenneth Blythe, John Hyde Mayo Canning, Saroj Kumar Das, Henry William Goodinge, Richard Winter Hase, Rio Nusservanji Mirza, Cedric Ormonde Vernon, Gerard Nunan Verver, Hendrik Adrian van de Wetering.

Companion.—John Fox.

Subscriptions

Under the Rules, members who have not paid their subscriptions for the current year by April 1st are not entitled to have the *Journal* sent to them. It is not always possible to send back numbers of the *Journal* to those who pay their subscriptions some time after April 1st, as many of the *Journals* go out of print.

The Council wish to thank all those members who have been prompt in paying their subscriptions. By the members supporting the Society in this way it is possible to legislate ahead and make arrangements which effect considerable savings against having to work from month to month.

Library

The attention of members is drawn to the rule that books may not be borrowed from the library for a period of more than three weeks. Many members, who borrow books, have not returned them until a request has been sent. This involves unnecessary work and expense and the Council have issued instructions that owing to the increasing demand for books the period of three weeks cannot normally be extended.

Acknowledgments

The Council gratefully acknowledge a number of back issues of the *Journal* from Miss L. Chitty, Associate Fellow.

Examinations

The next examination for Associate Fellowship and Associate Membership will be held on Monday, April 24th, 1933, in the offices of the Society.

"Aircraft Engineering"

The proprietors of *Aircraft Engineering* state that they are prepared to supply the paper monthly to Associates and Students of the Society at a special reduced subscription of 21/- per annum, post free. Subscriptions should be sent to the office of *Aircraft Engineering*, 6, Norfolk Street, Strand, London, W.C.2, and not to the offices of the Society.

Forthcoming Events

Thursday, April 6th.—Lecture by Dr. C. Dornier on " Lessons of the Do. X," in the Lecture Theatre of the *Institution of Civil Engineers, Great George Street, Westminster*, at 6.30 p.m.

Thursday, April 13th.—Lecture before Lincoln Technical College by Mr. J. T. Morton, A.F.R.Ae.S.

Thursday, April 27th.—Lecture by Mr. H. M. Garner, M.A., F.R.Ae.S., on " Seaplane Research," Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

MAY, 1933

Associate Fellowship and Associate Membership

The following important letter has been received by the President, from the Society of British Aircraft Constructors, the official body controlling the British aviation industry.

21st March, 1933.

Dear Mr. Fairey,—The Society of British Aircraft Constructors have followed with great interest for some years the constant efforts which the Royal Aeronautical Society have made to make Associate Fellowship and Associate Membership of the Society very real qualifications.

They are satisfied now that each grade calls for such experience, training and technical knowledge that, other things being equal, an Associate Fellow or Associate Member of the Royal Aeronautical Society should be chosen for a post in the Industry in preference to one not holding one of these qualifications.

Yours sincerely,

(Signed) (Sir) J. D. SIDDELEY,

Chairman.

This letter is an unequivocal acknowledgment of the status of the Society and the prestige of its Associate Fellowship and Associate Membership. During the past few years the regulations for joining in these grades have become more and more strict. The Council and their Grading Committee scrutinise every application with the greatest care and no one now can be elected to these grades who is not fully qualified for its particular work.

The acknowledgment of the Society of British Aircraft Constructors is an acknowledgment of the fact that those who are Associate Fellows and Associate Members of the Society will have better opportunities over those who are not.

The Council express the wish that members of the Society will draw the attention of non-members, who appear qualified to join, to this important letter and so strengthen the position of the Society.

Wilbur Wright Memorial Lecture

The 21st Wilbur Wright Memorial Lecture will be held in the Lecture Hall of the Royal Institution, 21, Albemarle Street, W.1, at 6.30 p.m., on Tuesday, May 30th, and will be followed by the Annual Council Dinner.

Before the lecture the various medals and prizes which have been awarded during the year will be presented.

The particular attention of all members is drawn to the venue of the lecture.

The lecture will be given by Colonel F. P. Lahm on "Training of the Airplane Pilot." Colonel Lahm is one of the three men who was chosen by the United States Government to be trained as pilots by the late Wilbur Wright.

Silver Medal

The silver medal of the Society has been awarded to Mr. A. H. R. Fedden, *Fellow*, for his work in air-cooled engines, and particularly for his work in connection with the attaining of the height record by Captain C. F. Uwins; and to Mr. D. L. Hollis-Williams, *Associate Fellow*, for his work in the design of the Fairey long-range monoplane which holds the world's long-distance record.

New Medals

Two new medals have been founded by the Society to be known as the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics. These medals have been founded following a request from Lord Amulree, when Secretary of State for Air, that the Royal Aeronautical Society should give some award for outstanding feats in aviation. A Committee was formed to consider the request of the Secretary of State, under the Chairmanship of the President of the Society, Mr. C. R. Fairey. After considerable discussion the Committee came to the following conclusions.

1. That a permanent Committee should be appointed to consider the awards of the medals. That this Committee should consist of six members of the Royal Aeronautical Society, and that the Chairman of the Royal Aero Club and the Air League should be invited to serve on it.
2. That the medals should be called the British Gold Medal for Aeronautics and the British Silver Medal for Aeronautics.
3. That the design of the Gold Medal should incorporate a portrait of Sir George Cayley and his first model aeroplane of 1804; that the design of the Silver Medal should incorporate the Henson and Stringfellow machines; that both medals should have on the reverse the peregrine and balloon emblem of the Society.
4. That the medals should be awarded for an achievement leading to advancement in aeronautical science.
5. That the award should be confined as far as possible to British Empire subjects, but other Nationals should not be excluded.
6. That the Committee should meet when their attention is drawn by the British Government to any meritorious achievement; when so directed by the Council; when their attention is drawn by the Royal Aero Club or the Air League to any meritorious achievement; or when their attention is drawn by any other recognised authority.

The expenses of founding these two important new medals are very heavy, and they have been generously defrayed by the President, Mr. C. R. Fairey. To the President is due entirely the successful conclusions of the conversations with the Secretary of State for Air, which have resulted in two new air awards that will not only be highly prized but will commemorate the outstanding British aeronautical pioneers, Sir George Cayley, so rightly called the father of aeronautics, and John Stringfellow and W. S. Henson.

The awards of these medals will be for an *achievement* leading to an advancement in aeronautical science, and this point of view will be constantly borne in mind whenever awards of the medals are under consideration.

British Silver Medal for Aeronautics

The first awards of the British Silver Medal for Aeronautics have been made for the following achievements which have led to advances in aeronautical science.

To Flt.-Lt. C. F. Uwins for reaching a world record height in a heavier-than-air craft of 43,976 feet on September 16th, 1932.

To Squadron-Leader O. R. Gayford, D.F.C., R.A.F., and Flight-Lieut. G. E. Nicholetts, A.F.C., R.A.F., who flew from Cranwell, England, to Walvis Bay, South Africa, non-stop on February 6th-8th, 1933, a distance of 5,340 miles.

Council Meeting

A Meeting of Council was held in the offices of the Society on Tuesday, April 11th, 1933.

Present: Mr. C. R. Fairey (President) in the Chair, Capt. P. D. Acland, Professor L. Bairstow (Vice-President), Major J. S. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Mr. A. H. Hall, Mr. J. E. Hodgson (Hon. Librarian), Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Capt. A. G. Lamplugh, Major R. H. Mayo, Mr. R. K. Pierson, Mr. E. F. Relf, Mr. L. A. Wingfield (Hon. Solicitor)

Among the business transacted was the following:—Preliminary Report of the Ground Engineers' Committee; the Award of the Silver Medal to Mr. A. H. R. Fedden, for his work in connection with the air-cooled engine and particularly the height record; and to Mr. D. L. Hollis-Williams for his work in the design of the Fairey long-range monoplane; the Report of the Finance Committee; the Report of the Grading Committee; the Election of Committees of Council; the Report of the Amulree Committee; a proposed Garden Party; arrangements for the holding of a Conversazione; the arrangements for the Wilbur Wright Memorial Lecture and Council Dinner.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 11th April, 1933:—

Associate Fellows.—Reginald Sydney Brown, James Alexander Cracknell.

Associate Member.—Laurence John West.

Associates.—Dermott Lang Allen, Roger Francis Bulstrode (from Student), William Albert Crabbs (from Student).

Students.—James Arthur Bailey, Percival Howard Beattie, George Robert Charles Blowers, Wilfrid Beaumont Dixon Box, J. R. Crean, Edgar Alexander Wright.

Lecture Suggestions

In May and June the Council and the Lectures Committee consider the programme of lectures for the coming Session. When the list of lectures is published there are always critics who say it is too scientific, too this or too that. The Council will be very glad to receive suggestions for lectures and will always give them very special consideration, as every effort is made each year to present a programme of lectures which will cover as wide a range as possible and be as helpful as possible. Suggestions should be received by May 30th at the latest.

Civil Air Display

The Guild of Air Pilots and Air Navigators of the British Empire are holding their second annual display at Brooklands on Saturday, May 20th.

The organisers would remind all interested that it is their dual object to provide an annual event of primary importance to the whole aircraft industry

and at the same time to establish on a permanent basis the Endowment Fund instituted in 1930 by the Guild's Honorary Wardens.

There is every promise this year of a first-rate programme, and every endeavour is being made to stress the civil application of flying.

Among items which will appear on the programme may be mentioned the following:—

New civil type machine park—take-off and climb.
Competition. Planette pylon racing—slow race.
Control of airport of the future—Concours d'Elegance, for the Tatler Cup and various demonstrations of a more technical nature.

At the same time R.A.F. support has been sought and promised, and one of the finest events will be that provided by a formation of fighters in flight aerobatics.

The Secretary of State for Air has kindly consented to open the Display, and the meeting has the active support of the Society of British Aircraft Constructors and the leading manufacturing and operating companies in the country.

Tickets 5/- and 2/6; motor cars 2/6. They will be available, if desired, beforehand, from the Organiser, Civil Air Display, 61, Cheapside, E.C.2. Telephone: City 1827, or at the gate on the day of the Display.

The late Mr. W. D. Batten

The late Mr. W. D. Batten, whose latest work on Wing Beats was described and illustrated in the Journal for February, 1933, has left behind apparatus which offers interesting possibilities. A number of readers of the Journal have expressed a hope that his experiments will be continued. If any one is interested enough to inquire further into Mr. Batten's apparatus will they please communicate with me? It is hoped that these interesting series of experiments will not be allowed to lapse without further investigation.

Acknowledgments

The Council gratefully acknowledge from Mr. W. O. Manning, *Fellow*, a set of Performance Charts of aeroplanes, seaplanes and ship aeroplanes of the war period and Abstracts from Aeronautical Patents for the years 1922-25. They also wish to acknowledge the presentation of two glass cases showing a sparrow hawk alighting and the spread wings of the black-headed gull and a prize carrier pigeon from Mr. P. Nazir, *Associate Fellow*; and from the Comper Aircraft Company three slides and photographs of the Comper Swift.

Forthcoming Events

Friday, May 5th.—Lecture before Kingswood Grammar School by Flight-Lieut. R. E. H. Allen, M.I.Ae.E., R.A.F.

Saturday, May 6th.—Students' Visit to the Royal Aircraft Establishment, South Farnborough, Aerodynamics Section.

Tuesday, May 16th.—Lecture before the Students' Section by Mr. D. Hay Surgeoner on "Aircraft Instruments." Mr. H. E. Wimperis, C.B.E., F.R.Ae.S. (Director of Scientific Research), in the Chair. In the Library of the Society at 6.30 p.m.

Saturday, May 27th.—Students' Visit to the Royal Aircraft Establishment, South Farnborough, Motor Testing Section.

Tuesday, May 30th.—Twenty-first Wilbur Wright Memorial Lecture by Colonel F. P. Lahm, Air Corps, U.S. Army, on "Training the Airplane Pilot." At the Royal Institution, 21, Albemarle Street, W.1, at 6.30 p.m.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

JUNE, 1933

Council Meeting

A meeting of Council was held on Tuesday, May 9th, 1933, in the Offices of the Society.

Present: Mr. C. R. Fairey, President, in the chair; Captain P. D. Acland, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Major R. H. Mayo, Mr. R. K. Pierson, Mr. D. R. Pye, Mr. F. Sigrist, Mr. O. E. Simmonds, Mr. L. A. Wingfield (Hon. Solicitor).

Among the business considered was the following:—The Report of the Finance Committee; the Report of the Grading Committee; suggestions for lectures for next session.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on 9th May, 1933:—

Fellow.—Paul Ward Spencer Bulman (from Associate Fellow).

Member.—Frederic William Haig (from Associate Member—Australasian Branch).

Associate Fellows.—Syed Maksood Ally, Frank Radcliffe (from Associate).

Associate.—Stephen Richardson.

Students.—Rodolphe Burford Broadhurst, Robert Knight Page.

Examinations

The following is an additional list of candidates who were successful in the recent examinations for Associate Fellowship and Associate Membership:—

ASSOCIATE FELLOWSHIP EXAMINATION.

Strength and Elasticity of Materials and Theory of Structures.—F. S. Dorabjee, C. H Hunter, J. A. Kelly, C. G. C. Leonard, W. P. Lewis, G. A. Mann, J. van Hattum.

Chemistry and Metallurgy.—F. S. Dorabjee, J. A. Kelly, P. N. Vincent.

Heat Engines.—C. H. Hunter, C. G. C. Leonard, W. P. Lewis, G. A. Mann, P. N. Vincent.

Aerodynamics.—J. van Hattum.

ASSOCIATE MEMBERSHIP EXAMINATION.

Design of Aircraft.—G. R. Irvine.

Air Transport.—G. R. Irvine.

Luncheon to Squadron-Leader O. R. Gayford and Flight-Lt. G. E. Nicholetts

A luncheon was given to Squadron Leader O. R. Gayford, D.F.C., A.F.C., R.A.F., and Flight Lieut. G. E. Nicholetts, A.F.C., R.A.F., holders of the world's long range record of 5,309 miles, on Thursday, May 18th, 1933, by the Royal Aeronautical Society, the Royal Aero Club, the Society of British Aircraft Constructors and the Air League of the British Empire.

The President of the Society, Mr. C. R. Fairey, M.B.E., F.R.Ae.S., was in the chair, supported by Lord Gorell, Chairman of the Royal Aero Club, Mr. H. J. Thomas, Chairman of the Society of British Aircraft Constructors, and Major-General the Right Hon. J. E. B. Seely, C.B., C.M.G., P.C., D.S.O., Chairman of the Air League of the British Empire

Among those who attended the luncheon were the following:—

Captain P. D. Acland, Patrick Alexander, Esq., Hon.F.R.Ae.S., C. V. Allen, Esq., Dr. Auranawski.

Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S., A. J. A. Wallace Barr, Esq., R. Blackburn, Esq., O.B.E., F.R.Ae.S., M.I.Ae.E., E. C. Bowyer, Esq., Major F. H. Bramwell, B.Sc., F.R.Ae.S., Sir Harry E. Brittain, K.B.E., C.M.G., LL.D., M.A., W. Broadbent, Esq., Major G. P. Bulman, O.B.E., F.R.Ae.S., Squadron Leader C. G. Burge, O.B.E., A.R.Ae.S.I., R.A.F. (Ret.), H. Burroughes, Esq., A.F.R.Ae.S.

G. Calder, Esq., Central News, Ltd., Representative, Air Commodore J. A. Chamier, C.B., C.M.G., D.S.O., O.B.E., A.F.R.Ae.S. (Secretary-General of the Air League of the British Empire), Flight Lieut. C. Clarkson, Squadron Leader S. N. Cole, A.F.R.Ae.S., R.A.F., Lieut. Comdr. C. N. Colson, A.R.Ae.S.I., R.N. (Retd.), William Courtenay, Esq.

Lieut.-Col. M. O. Darby, O.B.E., Squadron Leader C. J. W. Darwin, D.S.O., R.A.F., Wm. C. Devereux, Esq., A.F.R.Ae.S., Air Marshal H. C. T. Dowding, C.B., C.M.G. (Air Member for Supply and Research).

W. Lindsay Everard, Esq., M.P., Exchange Telegraph Co. Representative

Lieut.-Col. L. F. R. Fell, D.S.O., O.B.E., M.I.Mech.E., F.R.Ae.S., C. R. Field, Esq., Capt. A. G. Forsyth.

Air Commodore N. J. Gill, C.B.E., M.C., R.A.F., H. R. Gillman, Esq., A.F.R.Ae.S., Secretary of the Society of British Aircraft Constructors, Ltd., H. Gooding, Esq., the Lord Gorell, C.B.E., O.B.E., M.C., M.A. (Chairman of the Royal Aero Club), A. Gouge, Esq., F.R.Ae.S., C. G. Grey, Esq. (Editor of *The Aeroplane*), Loel Guinness, Esq., M.P.

A. G. Hazell, Esq., Flight Lieut. L. Massey Hilton, D.F.C., A.F.C., A.R.Ae.S.I., Commander Norman D. Holbrook, V.C., R.N., D. L. Hollis-Williams, Esq., B.Sc., A.F.R.Ae.S., B. E. Holloway, Esq., C.B. (Director of Contracts, Air Ministry), J. Hopcraft, Esq., A.M.I.Ae.E.

A. C. M. Jackaman, Esq., A.M.I.Ae.E., L. W. Johnson, Esq., M.C., M.Met., M.I.A.E., A.F.R.Ae.S., F. H. Jones, Esq.

Major D. H. Kennedy, O.B.E., F.R.Ae.S., Admiral Mark Kerr, C.B., M.V.O., R.N.

John Lord, Esq., F.R.Ae.S.

Capt. N. Macmillan, M.C., A.F.C., A.F.R.Ae.S., Sir F. K. McClean, A.F.C., A.F.R.Ae.S., Major R. H. Mayo, O.B.E., F.R.Ae.S., H. H. Morris, Esq., F. W. Musson, Esq., B.A., A.F.C., A.F.R.Ae.S.

W. H. Nicholl, Esq., A.M.Inst.C.E., Capt. D. Nicolson, A.F.R.Ae.S.

F. Handley Page, Esq., C.B.E., F.R.Ae.S., George Parnall, Esq., Major

R. E. Penny, O.B.E., F.R.Ae.S., H. E. Perrin, Esq. (Secretary of the Royal Aero Club), E. L. Pickles, Esq., O.B.E., A.F.R.Ae.S., N. A. V. Piercy, Esq., D.Sc., F.R.Ae.S., Ernest Pitman, Esq., Press Association Representative, Capt. J. Laurence Pritchard, Hon.F.R.Ae.S. (Secretary of the Royal Aeronautical Society).

Capt. H. C. Rawlings, D.S.O., R.N. (Director of the Naval Air Division, Admiralty), Reuters, Ltd., Representative, L. G. S. Reynolds, Esq., O.B.E., R. Rhodes, Esq., M.I.Ae.E., C. P. Robertson, Esq., M.B.E., F. Rowarth, Esq., N. Rowbotham, Esq., A.F.R.Ae.S., G. H. Russell, Esq.

Marshal of the Royal Air Force Sir John M. Salmond, G.C.B., C.M.G., C.V.O., D.S.O., LL.D., R.A.F., the Right Hon. Sir Philip A. G. D. Sassoon, Bart., G.C.B., C.M.G., M.P. (Under-Secretary of State for Air), Lord Herbert Scott, C.M.G., D.S.O., D.L., Major-General the Right Hon. J. E. B. Seely, C.B., C.M.G., P.C., D.S.O. (Chairman of the Air League of the British Empire), Sir John Shelley-Rolls, J.P., D.L., Lieut-Colonel F. C. Shelmerdine, C.I.E., O.B.E., A.F.R.Ae.S., Director of Civil Aviation, H. O. Short, Esq., F.R.Ae.S., Sir J. D. Siddeley, K.B., F.R.Ae.S., A. E. L. Skinner, Esq., M.C., A. E. Slater, Esq., Sir Harold E. Snagge, K.B.E., M.A., J.P., Lieut.-Comdr. the Hon. J. M. Southwell, A.F.R.Ae.S., R.N., Stanley Spooner, Esq. (Editor of *Flight*), T. Stanhop Sprigg, Esq. (Editor of *Air and Airways*), Flight Lieut. G. H. Stainforth, A.F.C., R.A.F., Flight Lieut. C. S. Staniland, A.R.Ae.S.I., B. Stevenson, Esq. (House Secretary, Royal Aero Club), Major Oliver Stewart.

Herbert J. Thomas, Esq. (Chairman of the Society of British Aircraft Constructors), *The Times* Representative, Major C. C. Turner, A.F.R.Ae.S.

Capt. C. F. Uwins, A.F.R.Ae.S.

Harry Vandervell, Esq., Sir A. Verdon-Roe, O.B.E., F.R.Ae.S., M.I.Ae.E.

Lord Wakefield of Hythe, C.B.E., Hon.LL.D., Hon.F.R.Ae.S., C. C. Walker, Esq., F.R.Ae.S., J. L. R. Waplington, Esq. (Secretary of the British Gliding Association), Capt. G. S. Wilkinson, M.I.Mech.E., F.R.Ae.S., Lawrence A. Wingfield, Esq., M.C., D.F.C., A.R.Ae.S.I. (Clerk to the Guild of Air Pilots and Air Navigators), G. E. Woods-Humphery, Esq., Squadron Leader Maurice Wright, A.F.C., A.F.R.Ae.S.

R. F. Youngman, Esq., B.Sc.

Associate Fellowship and Associate Membership

The following important letter has been received by the President, from the Society of British Aircraft Constructors, the official body controlling the British aviation industry.

21st March, 1933.

Dear Mr. Fairey,—The Society of British Aircraft Constructors have followed with great interest for some years the constant efforts which the Royal Aeronautical Society have made to make Associate Fellowship and Associate Membership of the Society very real qualifications.

They are satisfied now that each grade calls for such experience, training and technical knowledge that, other things being equal, an Associate Fellow or Associate Member of the Royal Aeronautical Society should be chosen for a post in the Industry in preference to one not holding one of these qualifications.

Yours sincerely,

(Signed) (Sir) J. D. SIDDELEY,

Chairman.

This letter is an unequivocal acknowledgment of the status of the Society and the prestige of its Associate Fellowship and Associate Membership. During the past few years the regulations for joining in these grades have become more and more strict. The Council and their Grading Committee scrutinise every application with the greatest care and no one now can be elected to these grades who is not fully qualified for its particular work.

The acknowledgment of the Society of British Aircraft Constructors is an acknowledgment of the fact that those who are Associate Fellows and Associate Members of the Society will have better opportunities over those who are not.

The Council express the wish that members of the Society will draw the attention of non-members, who appear qualified to join, to this important letter and so strengthen the position of the Society.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

JULY, 1933

President

At the Council Meeting held on June 20th, 1933, the Council unanimously re-elected Mr. C. R. Fairey, M.B.E., F.R.Ae.S., as President for a fourth year of office, October 1933-September 1934.

The Council wish to place on record their appreciation of the very great services Mr. Fairey has already rendered to the Society, and to voice their satisfaction that he has found it possible to agree to act for a further term.

Vice-Presidents

At the Council Meeting held on June 20th, 1933, Sir Robert Brooke-Popham, K.C.B., C.M.G., D.S.O., A.F.C., and Professor L. Bairstow, C.B.E., F.R.S., were unanimously re-elected Vice-Presidents for the year October 1933-September 1934.

King's Birthday Honours

Baron.—Major-General the Right Hon. J. Edward Bernard Seely, C.B., C.M.G., D.S.O., a Companion of the Society.

K.C.B.—Air Marshal Hugh Caswall Tremenheere Dowding, C.B., C.M.G., an Associate Fellow of the Society.

Council Meeting

A Meeting of Council was held in the Offices of the Society on Tuesday, June 20th, 1933.

Present: In the Chair, Colonel The Master of Sempill, Past President.

Among the business transacted was the following: The report of the Finance Committee; the appointment of a Solicitor to Aerial Science, Ltd., and Aeronautical Trusts, Ltd.; the report of the Grading Committee; the election of the President for 1933-34; the election of Vice-Presidents for 1933-34; the report of the Lecture Committee.

Elections

The following recommendations of the Grading Committee were approved by the Council at their meeting on June 20th, 1933:—

Fellows.—Francis Rodwell Banks (from Assoc. Fellow), James Douglas Kendall Restler.

Associate Fellows.—Henry Owen Baker (from Student), Graham Richards Dawbarn, Tulsi Dass Kumar (from Student), Frederick Alan Irving Muntz (from Associate), Harold Charles Pritchard, Juste Van Hattum, Henry Seddon Wildeblood (re-elected).

Associate Members.—Geoffrey Robert Irvine, Sidney Frederick Mitchell, Clifford Godfrey Rogers (from Associate).

Associates.—Stuart Heppolette King (from Student), Kawas Merji, Richard Courtenay Ilbert Pearse, Donald Teale Saville (Australasian Branch).

Students.—John Godsman Brown, Charles Clayton, Wallace Edward French, Terence Charles Harding, Arthur Henry Martin, Patrick Newton Vincent, J. Douglas Whitell, Robert Norman Wimshurst.

Companions.—Richard Meredith Alcock, John Edward Chorlton, Robert Frank Raymond Pierce (re-elected), Laurence M. Pinto (from Student).

Solicitor

The following is an extract from the Finance Committee Minutes approved by the Council at their meeting on Tuesday, June 20th, 1933:—

" The Committee RECOMMEND to Council that Mr. L. A. Wingfield, of Messrs. Wingfields, Halse and Trustram, 61, Cheapside, E.C.2, be appointed Solicitor to Aerial Science, Limited, and Aeronautical Trusts, Limited, on the understanding that he will attend meetings of the Council and the Finance Committee without remuneration.

" The Committee wishes to place on record and to draw the attention of the Council to their deep appreciation of the services Mr. L. A. Wingfield has rendered the Society during the years he has been Honorary Solicitor. During this time he has given his advice and time freely on many matters which have been of great benefit to the Society, including the completely revised Rules following the amalgamation with the Institution of Aeronautical Engineers, the formation of Aeronautical Trusts, Limited, the freeing of the Society from income tax and other legal matters. The Committee feel that in Mr. Wingfield they have someone who has the real interests of the Society at heart. They are finally of the opinion that in fairness to Mr. Wingfield the title Honorary should be dropped."

Acknowledgments

The Council gratefully acknowledge the following: A set of back numbers of the Journal from Mrs. Fullerton; slides of the Westland Wallace machine, including the machine used in the Mount Everest flight, from the Westland Aircraft Works; a copy of " The History of Aeronautics in Great Britain " (J. E. Hodgson), from Mr. R. F. R. Pierce.

The Council also gratefully acknowledge the gift, from Lieut.-Col. T. O'B. Hubbard, of a large number of air photographs taken by the R.F.C. on the Western Front. Many of these photographs are unique, and constitute a most valuable addition to the collection of photographs now in the possession of the Society.

Obituary

The Council have learnt with great regret of the death of A. P. Hall, a Student of the Society since 1931, who was drowned while bathing. They express their condolences to his parents on the great loss they have sustained.

J. LAURENCE PRITCHARD, *Secretary.*

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

AUGUST, 1933

August Bank Holiday

The Offices of the Society will be closed from Saturday, August 5th, to Monday, August 7th, inclusive.

Elliott Memorial Prize

The Elliott Memorial Prize has been awarded to Sergeant Apprentice A. J. Mason, at Halton.

Public Schools' Lectures

Arrangements are now being made for the delivery of a lecture to a number of Public and other schools, as in previous years. The subject chosen for the lecture this year is Seaplanes and Flying Boats, and will be illustrated with about 40 slides. The Council would be very glad to hear from any member of the Society who would be willing to help by giving one of these lectures to his old School, or to a school in his neighbourhood. During the past three years many members of the Society have given help in this way. Without such help, indeed, it would have been impossible for the Society to have met the enthusiastic and growing demand for these aviation lectures.

The lecturer is put to the minimum of trouble, the actual lecture is sent to him, together with the slides, a day or two before delivery, so he can make himself thoroughly familiar with the subject, and other slides are provided when required for any special reason.

Will any member who is willing to help the Society in this way write at once to the Secretary?

Lectures and Papers

The lecture programme for the 1933-34 Session is now in active preparation. The Council and the Lectures Committee have in the past received letters, when the programme of lectures has been published, suggesting that more of certain types of lectures should be given, particularly of a practical type, as opposed to the results of research type. The Council and Lectures Committee have only one object in view—to provide exactly that type of lecture for which there is the greatest demand.

The so-called " practical " lecture is, however, not one easy to obtain. It often makes the demand that a particular firm shall give away its methods of working, and this is one with which, often for reasons outside the firm's control (as, for example, that it is largely concerned with the construction of military aircraft), the firm is not able to comply. There is another reason against certain classes of lecture which are asked for, and that is that they do not lend themselves to an informative and useful discussion. Many of these suggested lectures, however, could very easily be cast in the form of a paper for publication in the

JOURNAL. The Council wish to urge upon all members of the Society that the JOURNAL is the medium for the publication of technical papers. The JOURNAL has a world-wide circulation, and papers which are published in it are in constant demand.

Major F. M. Green

Major F. M. Green, O.B.E., M.Inst.C.E., *Fellow*, is giving up his duties as Chief Engineer of the Armstrong Siddeley group of aircraft companies, a position he has held since 1917. Major Green entered aviation in 1910, when he became Engineer in charge of design at the Royal Aircraft Factory. In 1917 he joined the Siddeley Deasy Motor Company to help in the development of the B.H.P. engine, which, redesigned, became the Armstrong Siddeley Puma. It was followed by the Jaguar and other well-known types of Siddeley radials.

The Siskin, Atlas, Argosy and Atalanta were all produced under Major Green's supervision. Major Green proposes to act as a consulting engineer and to make a study of the practice of civil aviation both on the Continent of Europe and in America.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

SEPTEMBER, 1933

Lecture Programme, 1933-1934

The following lectures have been arranged for the coming Session:—

Thursday, 12th Oct.—Major R. H. S. Mealing, A.R.Ae.S.I., "Air Traffic Control."

Thursday, 2nd Nov.—Mr. W. G. Jennings, B.Sc., A.F.R.Ae.S., "Variable Pitch Airscrew and Variable Gears."

Thursday, 16th Nov.—Mr. H. Roxbee Cox, Ph.D., D.I.C., B.Sc., A.F.R.Ae.S., "The Stiffness of Aeroplane Wings."

Thursday, 30th Nov.—Dr. W. J. Duncan, "Tail Buffeting."

Thursday, 7th Dec.—Mr. A. H. R. Fedden, M.B.E., F.R.Ae.S., "Possible Future Development of Aircraft Engines."

Thursday, 14th Dec.—Dr. L. Aitchison, "Light Alloys for Aeronautical Purposes, with Special Reference to Magnesium."

1934.

Thursday, 11th Jan.—Mr. W. D. Douglas, A.F.R.Ae.S., F.R.C.Sc.I., "The Testing of Aircraft Landing Mechanisms and Some Factors Affecting Design."

Thursday, 8th Feb.—Captain A. G. Forsyth, "Engines."

Thursday, 8th Mar.—Joint Lecture with the Institute of Automobile Engineers and other bodies. Title to be announced later.

Thursday, 15th Mar.—Mr. H. J. Pollard, A.F.R.Ae.S., Wh.Ex., "Some Developments in Aircraft Construction."

Thursday, 29th Mar.—Mr. E. F. Relf, F.R.Ae.S., A.R.C.Sc., "Results from the Compressed Air Tunnel."

Public Schools Lectures

The Council wish to thank those members of the Society who have written, in response to the appeal made last month for lecturers, offering to give a lecture on behalf of the Society. The Council are particularly anxious that every member can feel he can help either in this or other ways. The success of the Society does not depend merely upon members paying their subscriptions. To a far greater extent it depends upon the enthusiasm of members. As a Royal society the Society is unable to advertise in many ways normally open to other bodies, and its chief advertisement must always come from its own members.

The Council are always anxious to encourage the giving of lectures on aviation. The Society has a collection of over 3,000 slides and many thousands of photographs from which slides can be made, and the slides are available to any member on payment of postage and acceptance of responsibility for broken

slides. Otherwise there is no charge. Information for the purpose of the lecture can also, in a great number of cases, be supplied.

Three standard lectures, together with 40-45 slides each, are now available:—

(1) The History of the Aeroplane.

(2) The Aeroplane and its Uses.

(3) Seaplanes and Flying Boats.

Acknowledgments

The Council wish to acknowledge a number of photographs of wartime aircraft from Mr. J. L. Nayler; and photographs and slides of amphibians from Messrs. Saunders-Roe.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

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MONTHLY NOTICES

OCTOBER, 1933

Council Meeting

A Meeting of Council was held in the Offices of the Society on Tuesday, September 19th, 1933.

Present:—Colonel the Master of Sempill (Past-President) in the chair. Captain P. D. Acland, Major G. P. Bulman, Mr. R. S. Capon, Major D. H. Kennedy (Hon. Treasurer), Mr. M. Langley, Mr. R. K. Pierson, Mr. D. R. Pye, Lieut.-Col. F. C. Shelmerdine, Prof. R. V. Southwell, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—Appointment of Representatives to the Aerodromes Advisory Board; the Report of the Finance Committee; the Report of the Grading Committee; Draft Deed of the Endowment Fund Trust; further lecture suggestions.

Aerodromes Advisory Board

Mr. C. R. Fairey, M.B.E., F.R.Ae.S., President, and Colonel the Master of Sempill, A.F.C., F.R.Ae.S., Immediate Past-President, have been appointed representatives on the proposed Aerodromes Advisory Board.

Elections

At a Council Meeting on September 19th, 1933, the following were elected:—

Associate Fellows.—John William Kidston Allsop, Alan D'Arcy Hodgson, Thomas Jones, Cecil Arthur Rea.

Associate Members.—George Adams, Alfred Reginald Code, Arthur de Terrotte Nevill, Harry Povey, Raphael Chevallier Preston (from Associate), Kenneth Darleigh Salmon.

Associates.—Leslie Crocker, Alan Harper Curtis, George Llewhellin Griffiths, John Balfour Murray (from Student), Erik Blyth Nelson.

Students.—Frederick Connop Behenna, Leonard Bloomer, John Nevil Breeze, George Arthur Day, Donald William Loveys Fairbank, Ronald Oliver Farley (Australian Branch), John Stewart Kirkwood, Anthony Ives Hostage Lynch, George Hennal Mansell, Ram Angrah Prasad Misra, Frank Sidney Parry, Robert Paton, Nariman Rustomjee, Terence Archibald Tobit, Graham Wilson Topping, Alfred William Woolgar.

Companions.—Hurll Fontayne Chester (from Student), Charles Wilfred Crossland, the Maharaja of Jodhpur, Ivor McClure.

Additional Lectures

The following lectures have been arranged in addition to those given in the Monthly Notices for September, 1933:—

January 18th, 1934.—Mr. F. Rodwell Banks, O.B.E., A.F.R.Ae.S., "Ethyl."

February 1st, 1934.—Mr. J. D. North, F.R.Ae.S., "Engine Cowlings."

Both these lectures will be held at the Royal Society of Arts, 18, John Street, W.C.2, at 6.30 p.m.

Advance Proofs

Advance proofs of lectures for the session may be obtained on a prepayment of 8s. od. for the whole session and 4s. od. for the half session, post free. Single copies for any particular lecture are 6d. each, or 7d. post free, and can be obtained from the Offices of the Society.

B.Sc. Examination, University of London

One of the recommendations of the Education and Examinations Committee was that steps should be taken to increase the facilities for aeronautical education. In November, 1932, a letter was sent to the University of London from which the following are extracts:—

"The President and Council of the Royal Aeronautical Society have had under consideration for the past two years the position of education in this country of aeronautical engineering. They wish to acknowledge the great help which the University of London has afforded in the rapidly developing subject of aeronautical engineering.

"The Council believe that the position has now reached a stage when a further step might with advantage be taken. In particular they have had under consideration the subject Mechanics of Fluids in the syllabus of the University and are strongly of the opinion that a revised syllabus for applied aerodynamics should be allowed as a whole subject in Group B of the B.Sc. engineering syllabus as an encouragement to aeronautical students."

In reply to the letter from the Council, the following letter has been received from the Secretary to the Academic Registrar:—

"With reference to your letter of 21st November, 1932, regarding the inclusion of Aeronautics in the syllabus of the Mechanics of Fluids at the B.Sc.(Eng.) Final Examinations for Internal and External Students, I am directed to inform you that the Academic Council, after report from the Boards of Studies concerned, have amended the syllabus in Mechanics of Fluids at the B.Sc.(Eng.) Examination for Internal Students to read as follows:—

THE MECHANICS OF FLUIDS

(Two papers).

Candidates will be required to offer either Section A, Hydraulics, or Section B, Aerodynamics.

Section A.—Hydraulics.

Pressure on stationary surfaces and centre of pressure. Buoyancy. Steady and unsteady motion. Bernouili's theorem. Venturimeter. Distribution of pressure and velocity in free and forced vortices. Laws of flow through orifices, mouth-pieces and notches. Velocity of approach. Laws of fluid friction. Viscosity. Theory of physical dimensions applied to

similar motions. The principle of dynamical similarity. Pressures on planes and bodies moving through a fluid. Resultant force and centre of pressure. Flow in pipes; frictional and other losses. Branched pipes. Flow in channels; ordinary form of channel.

River gauging; instruments and methods. Catchment areas; relation of rainfall and flow off ground. Storage and conveyance of water. Water supply and drainage. Impact of water on surfaces. Reaction of jets. Pelton wheel. Turbines and centrifugal pumps. Reciprocating pumps. Accumulators and intensifiers.

Section B.—Aerodynamics.

Airflow Theory and Experiment.—Relevant physical properties of the atmosphere. Laws of viscosity and the viscous stresses in two-dimensional flow. Aerodynamical applications of the Principle of similitude. Theory and practice of wind tunnel measurement; other experiments and important results. Theory and design of airscrews. Elements of potential flow. Single rectilinear vortex and vortex pair. Elements of Prandtl's aerofoil theory. Simple tunnel corrections. Boundary Layer and von Karman's theorem.

Aircraft Motion.—Forms of aircraft and choice of parts. Computation of drag. Equilibrium in steady rectilinear and circular flight. Speed range, useful load, rate of climb, ceiling. Prediction, testing and analysis of performance; Reduction to standard atmosphere. Simple manœuvres. Accelerometer reading and load factor. Nature of stability and disturbed aeroplane motion. Trim in relation to control and stability. Rolling moments and the dihedral angle. Autorotation. Full scale experiments.

This revised syllabus will come into force in 1935, but candidates may offer it in 1934 if they wish."

Acknowledgments

The Council gratefully acknowledge the following additions to the library and the Society's slide and photographic collections:—From Mr. R. F. R. Pierce, a copy of "Airsense," by W. O. Manning, from Dr. A. P. Thurston, Vol. I, No. 1, and Vol. I, No. 8, of the Institution of Aeronautical Engineers' Journal, and Vol. I, No. 2, and Vol. II, No. 4, and the Minutes of Proceedings, No. 16, of the Institution of Aeronautical Engineers; from Mr. G. E. Folkes, the Journal of the Society for 1918-1933; from Messrs. Saunders-Roe, slides and photographs of Saunders-Roe amphibians; from Armstrong Siddeley, Ltd., photographs of the construction of their aero engines.

Forthcoming Events

Thursday, Oct. 5th.—Lecture before the Gloucester and Cheltenham Branch by Captain J. Laurence Pritchard, Hon. F.R.Ae.S., on "Seaplane and Flying Boat Development."

Wednesday, Oct. 11th.—Lecture before the North Durham County Secondary Schools by Mr. E. G. Richardson, B.A., on "The Uses of the Aeroplane."

Thursday, Oct. 12th.—Lecture, "Air Traffic Control," by Major R. H. S. Mealing, A.R.Ae.S.I., in the Lecture Hall of the Royal Society of Arts, 18, John Street, W.C.2, at 6.30 p.m.

Friday, Oct. 13th.—Lecture before Haberdashers' Aske's Hatcham Boys' School by Mr. M. L. Bramson, F.R.Ae.S.

Saturday, Oct. 14th.—Lecture before Malvern College by Mr. F. Radcliffe, A.F.R.Ae.S.

Saturday, Oct. 14th.—Lecture before Brighton College by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Monday, Oct. 16th.—Lecture before Birkenhead School by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Tuesday, Oct. 17th.—Lecture before the Royal Masonic Senior School, Bushey, by Mr. H. R. Gillman, A.F.R.Ae.S.

Wednesday, Oct. 18th.—Lecture before Brentwood School by Flight Lieut. R. E. H. Allen, M.I.Ae.E.

Thursday, Oct. 19th.—Lecture before Ryde School, I.O.W., by Mr. T. A. S. Lloyd.

Friday, Oct. 20th.—Lecture before St. Albans School, Herts, by Lieut.-Cmdr. the Hon. J. M. Southwell, A.F.R.Ae.S.

Saturday, Oct. 21st.—Lecture before Sutton Valence School by Mr. J. E. Hodgson.

Saturday, Oct. 21st.—Lecture before Dover School by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Tuesday, Oct. 24th.—Lecture before the Students' Section of the Royal Aeronautical Society by Mr. E. V. Dolby, B.Sc., on "Air Transport Economy," in the Library, at 7 p.m.

Thursday, Oct. 26th.—Lecture before Hull Grammar School by Mr. H. V. Whiting, A.R.Ae.S.I.

Friday, Oct. 27th.—Lecture before Bristol Grammar School by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Monday, Oct. 30th.—Lecture before Tonbridge School by Mr. J. E. Hodgson.

Monday, Oct. 30th.—Lecture before Bermondsey Public Library by Wing Cmdr. T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S.

Tuesday, Oct. 31st.—Lecture before St. Paul's School, Kensington, by Mr. W. O. Manning, F.R.Ae.S.

J. LAURENCE PRITCHARD, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

NOVEMBER, 1933

Council Meeting

A meeting of Council was held in the Offices of the Society on Tuesday, October 17th, 1933.

Present: Air Marshal Sir Robert Brooke-Popham (Vice-President) in the chair; Captain P. D. Acland, Major J. S. Buchanan, Major G. P. Bulman, Mr. R. S. Capon, Mr. E. C. Gordon England, Mr. A. H. Hall, Mr. J. E. Hodgson (Hon. Librarian), Captain A. G. Lamplugh, Mr. M. Langley, Major R. H. Mayo, Mr. R. K. Pierson, Mr. D. R. Pye, Professor R. V. Southwell.

Among the business transacted was the following:—Appointment of Representatives to the Aerodromes Advisory Board; the Report of the Finance Committee; the Report of the Grading Committee; Appointment of a Representative on the Air League Council.

Elections

At a Council Meeting held on October 17th, 1933, the following were elected:—

Associate Fellows.—Hans Belart, George Reuben Brooke, Angus David McDowall, Richard Whitelegge O'Sullivan, Charles Harold Potts, Eustace Blewitt Robinson.

Associate.—Charles Edward Ward.

Students.—Habeeb Ahmed, Arthur Henry Davies, Denis John Milner Emerson, Edward George Fischeles, Charles Gerald Fisher, Alexander Jardine, Allan Thomas Oswald Liddell, Frederick Thomas Meacock, Peter Henry Milne-Milne, Leonard George Morris, Selwyn Cecil Perry, M. Pring-Rowe, Kaikhoshro Shapurji Saklatvala, Philip Garth Shott, Basil Robert Siminson, Arthur George Taylor, Leslie Ward.

Companions.—Robert Cecil Pierce, Edward Alfred Washer.

Examinations

Examinations for Associate Fellowship were held in the Offices of the Society on October 2nd. The following have satisfied the examiners in their respective subjects:—

Strength of Materials and Theory of Structures.—A. Davies, H. M. Kemp, J. T. P. Mihailov.

Aerodynamics.—H. E. Sturge.

Chemistry and Metallurgy.—J. T. P. Mihailov.

Air League of the British Empire

Mr. W. O. Manning has been appointed the Society's representative on the Council of the Air League in place of Mr. L. A. Wingfield.

Lecture Dinners

As last year the Royal Aero Club are arranging a late dinner for those who attend lectures of the Society. These dinners have been fixed at 2s. 6d. and members of the Society will be made honorary members of the Royal Aero Club

for those evenings. It is hoped that as many members of the Society as possible will take advantage of the facilities offered by the Royal Aero Club, whose address is 119, Piccadilly, W.1., telephone Grosvenor 1246-7-8.

Standard Lectures

The Society has prepared three standard lectures:—

1. The History of the Aeroplane.
2. The Uses of the Aeroplane.
3. Seaplanes and Flying Boats.

These lectures are each delivered with a set of 40-45 slides and take one hour to deliver. The first lecture largely deals with the history of British aircraft as does the third lecture. Other standard lectures are being prepared.

There is a very considerable demand for these lectures, which were written primarily for the public schools. They can all easily be modified for delivery to any audience.

The Council will be very glad to help any member who wishes to deliver a lecture either on the above subjects or any other subject in aviation. The Society has one of the largest collections of aeronautical slides, which is constantly being added to and kept up to date, thanks to the interest and generosity of firms in the industry. A list of slides is published, price 1s. 3d. post free.

Provided reasonable notice is given, the Society is prepared to select suitable slides for any particular lecture which a member may have in mind.

The only conditions for the loan of slides are that a member shall pay registered postage on them and replace any which are broken.

Students' Section

The following is a report of the activities of the students for the Session 1932-33.

At the annual general meeting held on Tuesday, October 25th, 1932, the following officers and members of committee were elected:—Chairman: Mr. J. N. Richmond; Vice-Chairman: Mr. S. D. Davies; Secretary: Mr. C. H. Jackson; Committee: J. P. Bertinart, V. A. R. French, H. G. Stokes, R. W. F. Farthing, G. P. King, R. J. Schmidt.

The inaugural lecture was given by Wing Commander T. R. Cave-Browne-Cave with Major T. M. Barlow in the chair.

In addition to the inaugural address five student lectures were given during the Session:—

Dec. 20th, 1932.—"Wing Slots," by B. Cornthwaite. In the chair, Mr. Handley Page, F.R.Ae.S.

Jan. 10th, 1933.—"Fuel Ignition in Compression Ignition Oil Engines," by W. H. Lewis. In the chair, Mr. H. R. Ricardo, F.R.Ae.S.

Jan. 31st, 1933.—"Detonation," by F. R. B. King. In the chair, Mr. H. T. Tizard, F.R.Ae.S.

March 7th, 1933.—"Dural in Aircraft Construction," by W. H. Lewis. In the chair, Lieut.-Col. W. Lockwood Marsh, F.R.Ae.S.

May 16th, 1933.—"Aircraft Instruments," by D. H. Surgeoner. In the chair, Mr. H. E. Wimperis, F.R.Ae.S., Director of Scientific Research.

The average attendance at these meetings was 18, a disappointing figure. Very distinguished members of the Society give their time to act as chairmen at these meetings, men who are world-wide authorities and from whom the students can obtain most valuable help. When chairmen of such high standing are willing to devote time they can ill spare to helping the students, it is the duty of every student to relegate into the background that night any other

interests and make a special effort to attend. Students sometimes complain that they do not receive sufficient attention. It is in themselves, however, to obtain exactly the attention they want, no more and no less. To interest the leading authorities in aviation they must themselves show interest.

Visits were paid, by courtesy of the firms concerned, to the Hawker Engineering Co., Ltd., the Fairey Aviation Co., Ltd., and Messrs. Short Brothers, Ltd., and also two visits to the Royal Aircraft Establishment. The visits, on the whole, showed a higher attendance than for the lectures.

During the year the Students' Committee asked for a member of Council to act as their representative and Mr. Langley agreed to act in this capacity.

Acknowledgments

The Council gratefully acknowledge the following additions to the library and the Society's slide and photographic collections:—From Mr. W. O. Manning, a copy of the first edition of the Airworthiness Handbook for Civil Aircraft, Private Flying Machines and L'Exploration par fusées de la très haute atmosphere et la possibilité des voyages interplanétaires, par R. Esnault-Pelterie; from Messrs. Popjoy, Ltd., the loan of engine photographs for slides; from Messrs. Rolls-Royce, Ltd., twelve slides of the construction of Rolls-Royce engines.

Aeronautical Books

Many members have suggested it would be a considerable help to them if aeronautical books could be obtained through the Society, as they often find difficulty in obtaining these books locally. The Society is in touch with most publishers of aeronautical books and books will be obtained on request.

Index of Aeronautical Reports

In December the Royal Aeronautical Society will publish the first of a series of annual volumes which will form an index of the International Reports and Memoranda. These volumes will keep everyone posted up to date with the latest reports on any aspect of the technical side of aviation in which they may be interested. They have been compiled on behalf of the Society of British Aircraft Constructors, for whom the Society is acting as publishers and will be invaluable records of material available.

Corrections

The following corrections in the article by Mr. Lockspeiser, "A Simple Approach to the Wing Flutter Problem," in the September issue of the JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY should be made:—

Page 784, sub-section 3, para. 2: (*a*) $\dot{z}/\dot{V}$ should read $\dot{z}/V$. (*b*) $(z/\dot{V})\,V^2$ should read $(\dot{z}/V)\,V^2$. (*c*) zV should read $\dot{z}V$.

Page 787, line 9: $\ddot{Z}$ should read $\ddot{z}$.

Forthcoming Events

Thursday, Nov. 2nd.—Lecture, "Variable Pitch Airscrews and Variable Gears," by Mr. W. G. Jennings, B.Sc., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 2nd.—Lecture before the Yeovil Branch by Mr. Gibson on "Press Work."

Thursday, Nov. 2nd.—Lecture before the City of London Freemen's School by Mr. N. A. C. Champion, A.M.I.Ae.E.

Thursday, Nov. 2nd.—Lecture before the Grammar School, Newcastle-on-Tyne, by Mr. E. G. Richardson, B.A., Ph.D., M.Sc.

Monday, Nov. 6th.—Lecture before the Hillingdon Council School by Mr. J. T. Morton, A.F.R.Ae.S.

Tuesday, Nov. 7th.—Lecture before the Bristol Branch by Squadron Leader O. R. Gayford, D.F.C., A.F.C., R.A.F., on "The Long Range Flight."

Wednesday, Nov. 8th.—Lecture before Alderman Newton's School, Leicester, by Lieut. C. W. Phillips, R.N.

Friday, Nov. 10th.—Lecture before Wyggeston School, Leicester, by Lieut. C. W. Phillips, R.N.

Friday, Nov. 10th.—Lecture before King's School, Rochester, by Mr. C. P. T. Lipscomb, A.F.R.Ae.S.

Friday, Nov. 10th.—Lecture before the Workers' Educational Association, Chester-le-Street, by Mr. J. Bell, A.R.Ae.S.I.

Wednesday, Nov. 15th.—Lecture before Upton College, Bexley Heath, by Mr. J. T. Morton, A.F.R.Ae.S.

Thursday, Nov. 16th.—Lecture, "The Stiffness of Aeroplane Wings," by Mr. H. Roxbee Cox, Ph.D., D.I.C., A.F.R.Ae.S., in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 16th.—Lecture before the Yeovil Branch on "The Developments of Oil Engines," by Mr. Dicksee.

Friday, Nov. 17th.—Lecture before the Royal Grammar School, High Wycombe, by Major D. H. Kennedy, O.B.E., F.R.Ae.S.

Friday, Nov. 17th.—Lecture before Durham School by Mr. J. Bell, A.R.Ae.S.I.

Friday, Nov. 17th.—Lecture before Kingswood Grammar School, Bristol, by Flight Lieut. R. E. H. Allen, A.M.I.Aut.E., M.I.Ae.E.

Friday, Nov. 17th.—Lecture before Gillingham Council School for Boys by Mr. C. P. T. Lipscomb, A.F.R.Ae.S.

Saturday, Nov. 18th.—Lecture before Dean Close School, Cheltenham, by Flight Lieut. R. E. H. Allen, A.M.I.Aut.E., M.I.Ae.E.

Saturday, Nov. 18th.—Lecture before Stamford School, Lincolnshire, by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Saturday, Nov. 18th.—Lecture before King's School, Worcester, by Mr. F. Radcliffe, B.Sc. (Hons.), A.F.R.Ae.S.

Monday, Nov. 20th.—Lecture before Cambridge and County School by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Tuesday, Nov. 21st.—Lecture before the Manchester Branch by a Member of the Staff of Short Brothers, Ltd., on "Flying Boats."

Tuesday, Nov. 21st.—Lecture before the Bristol Branch by Mr. G. O. Waters, on "The Empire's Airway."

Wednesday, Nov. 22nd.—Lecture before Germain's Senior Boys' School, Chesham, by Captain A. B. Fanstone, M.A., A.F.C., A.F.R.Ae.S.

Friday, Nov. 24th.—Lecture before Rutherford College, Newcastle, by Mr. J. Bell, A.R.Ae.S.I.

Monday, Nov. 27th.—Lecture before St. Olave's School, Tower Bridge, by Captain J. Laurence Pritchard, Hon.F.R.Ae.S.

Tuesday, Nov. 28th.—Lecture before King Edward VII.'s School, Southampton, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E.

Thursday, Nov. 30th.—Lecture, "Tail Buffeting," by Dr. W. J. Duncan, in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, at 6.30 p.m.

Thursday, Nov. 30th.—Lecture before the Yeovil Branch by Mr. J. C. Jennings, on "An Insight into Petroleum."

Thursday, Nov. 30th.—Lecture before Peter Symonds School, Winchester, by Wing Commander T. R. Cave-Browne-Cave, C.B.E., F.R.Ae.S., M.I.Mech.E.

J. Laurence Pritchard, *Secretary*.

THE

ROYAL AERONAUTICAL SOCIETY

With which is incorporated the Institution of Aeronautical Engineers

MONTHLY NOTICES

DECEMBER, 1933

Office Closing

The offices will be closed from Saturday, December 23rd, 1933, to Tuesday, December 26th, 1933, inclusive, for the Christmas holidays.

Council Meeting

A Meeting of the Council was held on Tuesday, November 14th, 1933, in the offices of the Society.

Present: Mr. C. R. Fairey (President) in the chair; Captain P. D. Acland, Major J. S. Buchanan, Major G. P. Bulman, Mr. A. H. Hall, Major D. H. Kennedy (Honorary Treasurer), Captain A. G. Lamplugh, Mr. M. Langley, Mr. D. R. Pye, Lieut.-Colonel Shelmerdine, Mr. F. Sigrist, Mr. O. E. Simmonds, Professor R. V. Southwell, Mr. L. A. Wingfield (Solicitor).

Among the business transacted was the following:—A vote of sympathy to Colonel the Master of Sempill (Past-President); Airports Conference at the Mansion House on December 8th; an Endowment Fund Trust Deed; Flying Facilities for Student Members of the Society; Dinner of the Parliamentary Air Committee.

Christmas

The President and Council wish all members of the Society a very happy Christmas and a prosperous New Year. The past few years have been difficult ones, but they have every confidence that progress in the air will show a definite advance in 1934. They wish particularly to thank every member of the Society for their helpful support during the past three years.

International Index

An International Index to Aeronautical Technical Reports has been prepared by the Society of British Aircraft Constructors, Ltd., and is published by the Society this month at 5s. net. It consists of 132 pages bound in cloth, and is an index of British, American and Foreign Technical Reports. Specimen pages of the Index are inserted in this issue of the Journal, which will give an indication of its scope.

It is hoped to publish the Index annually and so keep all members in touch with the latest references to reports, papers and articles of an aeronautical technical nature throughout the world. The report can be obtained from these offices, price 5s. or 5s. 3d. post free.

Wakefield Lecturer in Aeronautics

Lord Wakefield has undertaken to provide funds for a special lecturer in aeronautics for a period of three years in connection with the course in that subject at University College, Hull. The salary offered is £450 per annum together with a contribution of 10 per cent. by the College towards superannuation.

Applications should be made to A. E. Morgan, Principal, University College, Hull.

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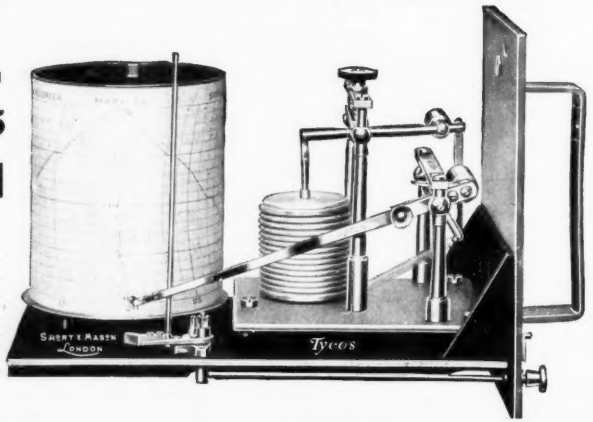

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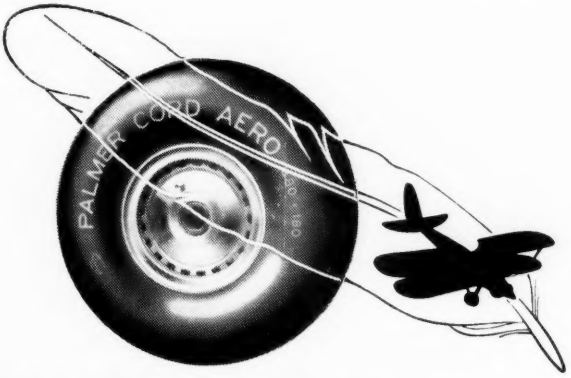

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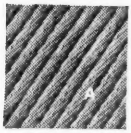

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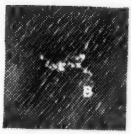

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in 1897 in succession to the* ANNUAL REPORTS.

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The Journal is published monthly at the Offices of the Society, 7, Albemarle Street, Piccadilly, London, W.1.

Telephone: Regent 6800. Telegraphic Address: "Didaskalos, Picc, London."

Subscription per annum, £2-4-6 post free; Single Numbers 3/6, or 3/9 post free.

All communications for publication in the Journal, or on general matters affecting the Society should be addressed to—

The Secretary and Editor,
J. Laurence Pritchard,
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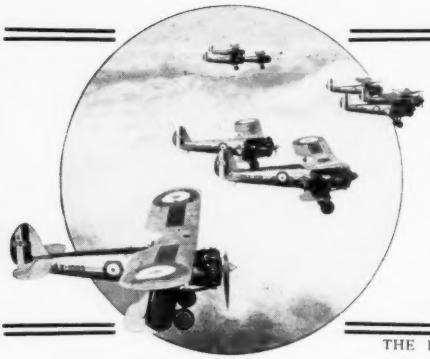

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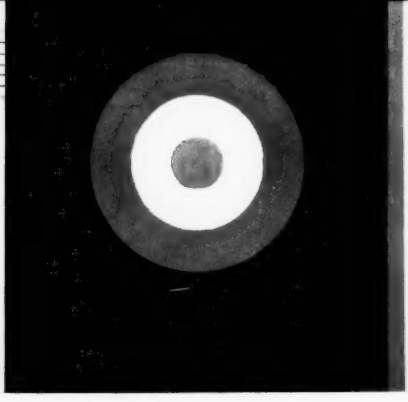

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